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EMOTION AND PERCEPTION FROM THE BEHAVIORIST STANDPOINT

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The future of behaviorist psychology will depend on the success with which it treats the specific phenomena of consciousness. To rest its case on the general theoretical advantages, important though they may be, of defining consciousness in terms of behavior, would be to forego the chief claim of any theory to scientific recognition: methodological fruitfulness. At present behaviorism is a program rather than an achievement; a method of approach rather than a theory possessing scientific credentials. Those of us who are most impressed by the importance of the philosophical advantages behaviorism offers, and who see, or think we see, great promise in its program of reconstruction, are impatient to see the program carried out. Why dally over the definition of consciousness? The progress of biological science has not depended on the formulation of an adequate definition of life. It has, indeed, depended on replacing the belief that a living being is a corporeal object endowed with a vegetable or animal soul, with the conception of it as an organized structure capable of maintaining a system of cyclical activities. The attainment of this conception has been absolutely essential to the development of biology. It has offered a program and a method of approach comparable to that which behaviorism claims to offer today. But the progress of biology has consisted in the exhibiting of the characteristic activities of the living being as elements in that cyclical system. Instead of defining life, biology has been occupied

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in investigating the specific processes of living, and in tracing their mutual relations. To a similar occupation behaviorism must henceforth devote itself.

So far the behaviorist movement has had two distinct, if not wholly independent, sources. On the one hand, we find a group of experimental investigators of animal behavior, occupied with such problems as that of determining what mode of response, if any, is called out in a given species by a given physical stimulus; how given types of reaction are excited, and how they are modified. On the other hand, we find a group of philosophical behaviorists, who are chiefly concerned with the metaphysical aspects of the new doctrine and who devote themselves almost exclusively to the task of defining consciousness in terms of behavior. The two groups of thinkers find a common ground in their conviction that the study of mind and the study of behavior are not two things but one, and that the investigation of the so-called phenomena of consciousness can be fruitfully carried on only through the study of behavior.

But while the experimentalists are occupied with the reactions of the lower animals, and the philosophers with the definition of consciousness, the classical categories of psychology—sensation, perception, emotion, affection, volition, thought, etc.—are left almost wholly to the undisputed sway of the traditional psychology.[1] Has behaviorism no use for these categories? If it be true, as is sometimes implied, that the ideal of the science of behavior is the ability to predict what muscular contractions a given animal will make under given conditions, the psychological categories may well be neglected. But that ideal, at least in the case of the higher animals, is an unattainable one; and, what is more important, if it were attained it would leave most of the behavior of those animals, and particularly of human beings, unintelligible to us. In order to understand behavior we must resolve

[1] This statement seems less true today, as proof of this article passes through my hands, than it appeared to be when these lines were written. Evidence is accumulating that the experimental behaviorists have already broadened the field of their interest. Witness, for example, the investigations by Professor Watson of emotion in infants, published in this REVIEW, May, 1919.

it into a system of interrelated *functions*, just as in order to understand the physiological workings of the human body we must envisage the complex of chemical and mechanical processes as falling into such functional groups as digestion, circulation, etc., constitutive of the physiological economy. Now just as there is a physiological economy, so there is a larger vital economy, in closest union with, yet distinguishable from it. This is the system of behavior, by means of which the being, animal or human, maintains his relations with the environment and forms a factor in its transformation. The science of behavior has the task of tracing the lineaments of this larger economy. This economy is actually carried on, to be sure, by means of muscular contractions, or, if you please, by means of chemical reactions; but just as truly, and far more significantly, must it be said to be maintained by the performance of such functions as instinct and habituation, perception and emotion, or even memory and thought.

We should be rash, indeed, to assume that a scientific analysis of behavior would reveal the presence of all the classes of phenomena recognized by traditional psychology. What we have to expect is the discarding of some and the modification of many, as well as the discovery of a certain number of new psychological categories. But if behaviorism is to fulfill its promise, it must deal definitively in some manner with the classical phenomena of psychology.

It would be wrong to assert that nothing has been done in this direction. We are in possession of at least the outlines of a behaviorist theory of perception. But there has been little progress toward a larger systematic account of psychological phenomena. And yet there are many problems for which, it would seem, the materials for a solution, or at least for a profitable discussion, were at hand. How, for example, are the general functions of cognition and affection related to each other? More specifically, how is perception related to emotion? What distinctive place has each in the economy of life? On this problem it would seem that behaviorism is able to cast a flood of light.

It is evident, to begin with, that emotion is closely con-

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nected with distinctive bodily activities in a way in which perception is not. One may readily tell from the behavior of a man or animal, especially from his attitude or expression, that he is angry or afraid; while the fact that he is intent upon the sight and smell of smouldering fire is not evident to one observing his demeanor. As the difference has sometimes been imperfectly characterized, one is active in emotion and passive in perception. Using the language of a more recent terminology, the generalization might be made that an emotional state is conditioned by specific types of response (including organic disturbance) and is relatively independent of the specific nature of the sensory stimulus, while perception is conditioned by the specific sensory stimulus and is relatively independent of the specific nature of the response. For example, fear may be aroused in a child by the sight of some strange animal, by loud and startling sounds, by the sudden seizure of its arms, etc., and on each occasion it may exhibit its terror in much the same way, *e.g.*, by crying and struggling to hide its face in its mother's skirt. On the other hand, the perception of the mother can be experienced only if the appropriate stimuli of light, etc., are acting on its sensory end-organs, while the response to such stimulation may vary indefinitely.

Such a generalization in regard to the relation of emotion to perception is obvious; but it does not carry us very far. It does serve, however, to set the problem a little more specifically. Since the rejection by psychology of the formerly alleged 'innervation feeling,' the general assumption has been that experienced content is determined by sensory stimulus in independence of motor discharge. Indirectly, indeed, the response has been supposed to play a part, and a very important part, in so far as the movements of the response arouse fresh sensory stimulation. But motor nervous activity itself has been regarded as wholly inoperative in determining content. Accordingly, the fact that emotion is connected with characteristic bodily reactions has led the psychologist to find the content of the emotional state in the sensory excitations arising from the emotional response

itself. Thus, to use James's familiar example, what the grieving mother experiences is the coldness and clamminess of her skin, the distortion of her face, her labored breathing, etc. Similarly, *what* we feel when we are angry or afraid is the mass of bodily and organic sensations aroused by tensed muscles and unusual organic activity. Our generalization that emotion differs from perception in being conditioned by response rather than stimulus, is displaced by the generalization that the content of emotion is determined by proprioceptive sensory stimuli while that of perception is commonly exteroceptive. This proposition, however, is evidently insufficient to distinguish emotion from perception. Emotion is not a mere perception of bodily activity. In addition to the sensory elements of emotion it has been customary to accept an ultimate feeling-tone, or affective element. The nature and number of affective elements has been a notorious bone of contention; and, moreover, there has been no agreement, and usually no clear-cut doctrine, as to the so-called neural correlate of affection. But it is significant that it has usually been held to depend on the general bodily or nervous condition, such as 'depression' or 'excitement,' rather than on a specific nervous discharge. The uncertainty and disagreement on this point is certainly a symptom of systematic weakness. If affective content is admitted to vary with general nervous condition or state of activity, the assumption that the motor discharge following a given sensory excitation plays no direct part in determining content becomes highly questionable.

There is a further distinction between emotion and perception which, while less obvious, is familiar to psychologists, and which is of the greatest significance. It is the characteristic difference between them in their relation to attention. The content of perception is marked by varying degrees of attentive clearness. This is not true of an emotional state. Indeed it might be said that emotion has no content in the sense in which it may be ascribed to perception. When the attempt is made to observe an emotion introspectively, the emotion vanishes, and one finds oneself noting the beating

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of one's heart, or the strain in the back of one's neck, or some such item of bodily condition. It is essential to the maintenance of the characteristic emotional 'tone,' that these proprioceptive sensations should remain in the margin of attention. What occupies the focus in the emotional state is the object to which the emotion is directed, or, to use the traditional term, the externally excited sensations which form the content of perception. So soon as the organic and kinæsthetic elements shift to the focus of attention, they become thereby elements of a new perceptual content (the body). In order that the emotion should persist the attention must be fixed upon the content of perception.

This, then, is the crux of the matter. Since in emotion attention is directed to the perceived object arousing the emotion, we must ask how such an object is experienced as different from the object which is merely perceived and not emotionally responded to. It is in the object upon which attention is fixed and which is controlling behavior, that we must look for the content of the emotion, and not in the body. It is only the intellectualism of the theorizing psychologist that has found it in the latter place. That the object which excites rage, or fear, or love does *eo ipso* possess its specific quality, language abundantly testifies. The person with whom we are deeply angry is 'hateful,' and we call him so. The glance of his eye, the turn of his head, the tones of his voice are charged with this hatefulness. The object that inspires us with fear is a 'terrible,' or 'fearful,' object. The rumbling of the thunder is 'ominous'; and the coiled snake is 'loathesome.'

These qualities of things, which are discovered to us in states of emotional excitement, I shall call 'affective qualities' (to distinguish them from perceptual qualities and properties, such as shape, size, texture, color, etc.). It is these that form the content of emotion. It is these that we are aware of, or feel, in our emotional states, and not the organic activities and muscular tensions. It is true that momentarily there may flash up into consciousness the beating of one's heart, or the sinking in the pit of one's stomach; but it is not

these momentary flickerings of attention that are constitutive of the essential peculiarity of the emotional state. The field of consciousness is never steady in normal life, but is constantly streaked across with flashes and flickerings which mark the pulses and variations in nervous functioning. To feel emotion is to be aware of the affective quality of the object or event arousing the emotion. And, conversely, to become aware of such an affective quality in an object is to be emotionally aroused toward that object.

It will help to prepare the way for the account of emotion which I wish to present, if we pass in brief review some related and contrasted points in other theories. Of the classical school of analytical psychologists, who hold that all conscious phenomena are analyzable into complexes of processes, little need be said. According to this school, emotion and perception are alike complexes of sensation. Emotion is distinguished in that (1) there is a strong affective coloring of pleasantness or unpleasantness, (2) the sensations making up the complex are largely organic and kinæsthetic, (3) the emotion-complex is never in the focus but always in the margin of attention. In emotional states (at least of a primary sort) the focus is occupied by a perception-complex. It is for this reason that, when one tries to observe an emotion introspectively, the emotion disappears and one finds oneself attending to some item of bodily condition; *i.e.*, the marginal sensations constitutive of the emotion have become focal and *ipso facto* perceptual. It only remains to add that this school takes no account of the affective qualities which are immediately experienced as inhering in the object exciting the emotion.

The other classical school, which takes as its point of departure, not the idea of *process*, but the idea of *awareness*, holds all conscious phenomena to be resolvable into the act of awareness *plus* the content of which one is aware. There is a divergence of opinion among the members of this school, some holding that differences in conscious phenomena, notably in the case of desiring and willing, are due to differences both in the kind of act and in the content; while others

reduce all differences in the phenomena to differences in content. Among these latter, so far as their psychological affiliations are concerned, are the American neo-realists, who are of peculiar interest to us in that they identify the act of awareness with selective activity of the nervous organism in responding to those features of the environment and body which act as stimuli. Thus, according to them, to react to a stimulus is to be aware of that stimulus. The variety in conscious life, then, and even what we may call the structural complexity of experience, is put on the side of content. This method of treatment, which lumps together all classes of behavior as response to stimulus and equates this with a simple awareness, tends to obliterate the empirical differences between such phenomena as emotion and perception. Thus the dog, circling around his adversary for attack, is responding to the physical properties of his enemy, such as his shape and size and the sounds he emits; but he is also responding to a no less real property, the *inimicalness* of the enemy, or his *hatefulness*. So, when we shudder with fear at the coiled snake, the neo-realist would describe our experience as a response to, *i.e.*, an awareness of, the dreadfulness or loathesomeness of the reptile, just as our vision of the coils and the glisten is a response to, or an awareness of, those physical properties.

Now this neo-realist theory is so far similar to the behaviorist view which is to be presented here, that it recognizes the existence of affective qualities and treats emotion as the experience of these qualities. But intent upon his general philosophical position, the neo-realist has failed to take account of the very distinction which sets our problem. So far as I know, no attempt has been made by him to explain how such a property as the loathesomeness of the reptile is related to such sensible properties as its glisten and its shape. These perceptual properties may be correlated more or less indirectly with physical stimuli, but it would be impossible to equate the loathesomeness with a determinate type of physical stimulus. Furthermore, the neo-realist has not made clear what part, if any, he would give to the alleged

proprioceptive sense-data (I use his own terminology) in emotion. If present at all as content, they must, on the neo-realist view, be present in the same way and stand on the same footing as the perceived sensory qualities. What the neo-realist is interested in is the ontological status of such properties as *loathesomeness* and *hatefulness*. The goal of his endeavors is to exhibit them as objectively real, as properties belonging to the independent world, brought within our ken by the selective activity of the nervous system. Their distinctive character he ignores.

Different in background and method as pragmatism is from neo-realism, there are affinities between them in certain respects which have been the subject of considerable discussion. The particular point of interest to us is the pragmatist's realistic treatment of what I have called affective qualities. "Things are," says Professor Dewey, "what they are experienced *as*." The windowshade flapping in the night, which is invested with nameless terrors before I discover it to be nothing but the shade blown by the wind, is as really 'fearsome' as it is 'loud' or 'intermittent.' So the snake is really 'loathesome,' the castor oil 'nasty,' the fire in the grate 'cheerful.' What properties things have is, according to Professor Dewey, as truly determined by, as determinant of, the response they make. The process of determining the response, which constitutes the act of perception, is at the same time the process of determining the stimulus.

Thus the pragmatist, like the neo-realist, tends to treat emotion as the perception of a certain class of attributes, such as hatefulness, loathesomeness, etc., which may be termed affective. What they both have failed to realize, or at least to take adequate account of, is the very real and important distinction between such affective attributes of things and what are commonly regarded as objective properties, such as shape, or size, or texture, the objects of perception proper. The coiledness of the snake has a determinateness, a sort of fixity and solidity, which its loathesomeness lacks. It lends itself to description, to the noting

of detail. The loathesomeness on the contrary, cannot be described; it presents no detail; it can only be felt as ultimate unanalyzable *this*. Moreover, it cannot be attended to in the same way. It either vanishes upon persistent scrutiny into mere shine and glisten and shape, or it overwhelms one with a shuddering. One catches it evanescently in the slimy glisten and slow movement, but it is not these nor anything qualitatively determinate. *Mutatis mutandis*, the same thing is true of that nameless overpowering charm which the beloved has for the lover. To the bystander or to the would-be sympathetic friend, the other's beloved may be fair and lovely, as many other women may be; but that peculiar charm which the lover celebrates can be experienced only by himself. To fall in love is precisely to become aware of this unique and inexplicable charm which sets her apart from all others. One could not experience this quality, indeed, without loving her. Like the loathesomeness of the slimy snake, this quality is featureless. One may catch it in the turn of the head, the tone of the voice, or in a hundred other perceived details; but it is none of these. One can only feel it.

It is evident that these affective qualities have distinctive characteristics, which a simple act-content theory is unable to take account of, and which pragmatism has neglected. Whatever their metaphysical status—and with that we are not here concerned—their empirical psychological status differs in important respects from that of the perceptual properties.

For these differences behaviorism provides an ample ground of explanation. Starting as it does with the assumption that experienced content is not determined directly or alone by the sensory stimulus, but varies also with the system of motor response brought into play, that is, with function rather than with process, it finds a natural way of accounting for the existence of affective qualities and a ground for distinguishing them from perceptual properties. The object which is experienced as fearful owes this affective quality of fearfulness to the fact that the sensory stimulus is arousing the specific response of fear. Now this response, while

it is specific, is not an invariable set of muscular contractions and organic reactions. Even though we recognize by the unmistakable demeanor and 'expression' that the child or the dog is afraid, we find the task of definite and detailed description of the criteria of fear extremely difficult. What the recent researches of Cannon and others have brought out is that in all strong emotion there are characteristic organic disturbances, notably the activity of the ductless glands, which have the effect of releasing stores of latent energy for the immediate utilization of the voluntary muscles, while the digestive processes are inhibited. That is, the function of emotional excitement is the sudden energization of the body. This is, of course, very important information; but it has in itself no bearing on our problem. So far research has failed to reveal any specific differentia of fear or rage. No activity, either organic or muscular, is universally present in all cases of fear or is peculiar to fear. The particular reaction brought out on any occasion of fear may be headlong flight, frantic struggling, or the trembling suspension of all overt activity. All these as well as other activities are currently recognized as fear-responses, and rightly, because they all belong to a single system of alternative responses, genetically and functionally bound together. They are functionally related in that they normally serve the common end of escape from danger. They have probably arisen as differentiations and modifications of some simpler reaction, or reactions; and they retain the mark of their common descent in the ease with which one form of reaction passes into another, trembling inactivity into stealthy crouching under cover, or this into headlong flight and calls of distress. Any stimulus that brings into play this system of alternative responses is experienced as fearful. The common and distinctive character of the emotion of fear is not to be found in any set of organic and kinæsthetic 'sensations' excited by the emotional reaction. If such sensations were present they would vary too much from occasion to occasion to account for the identity of the emotional content. The identity of the fear-experience is to be found, not in any

identity of separate sensory or motor elements of the varying nervous activity, but in the unity of the total functional system brought into play. The activity of this specific system of fear is, as it were, projected upon the exciting object and incorporated in it as the affective quality of fearfulness. Hence, in spite of the enormous differences in the sensory stimuli coming from feared objects, they are experienced as in so far alike.

Perception, in contrast with emotion, involves no specific response, in the sense just described, at all. Yet to say that perception has no function in the determination of response, or is not itself an element of behavior, would be false. No one would today claim that perception is a mere passive receptivity to sensory stimuli. On the contrary, it is just its part in the determination of response that is its essential characteristic. Professor Dewey has described it as the act of 'constituting the response.' In perception we take an attitude of readiness to respond to the perceived object in a way not yet fully determined. We perceive, in other words, what we are attending to and just in so far as we are attending to the thing in question. Now attention involves the postponement of response, and the possibility of the selection of alternative modes of response. There is, indeed, a sort of response which is going on during the period of attention, *i.e.*, the adjustment of sense organs to further and fuller excitation from the exciting source—the cocking of ear, the tension of head and neck muscles, the fixing of eye, etc., which characterize the attentive attitude. The prolonged excitation which comes pouring into the cortical centers from the perceived object thus has opportunity to bring into tentative activity the whole repertoire of muscular reactions and, by mutual inhibition and reinforcement, to constitute the final response. What Professor Dewey has pointed out is that this process is a reciprocal one, and that the constitution of the response is at the same time the constitution of the stimulus, considered as a psychological factor. Aside from the part the stimulus has in the total nervous activity, it is merely a physical event. It is *psychological* only in so far as it is a functional element.

If this is true, the perceptual qualities of things are not determined by the nature of the stimulus considered as excitation of end-organ or sensory center. We are in the habit of thinking of sameness of perceptual content as being sufficiently conditioned by sameness of sensory stimulus, but a little reflection shows that this assumption is far from true. We may see and recognize the same house, the same landscape, the same face on different occasions, although the actual visual stimuli acting on retinal end-organs vary widely from occasion to occasion. Moreover, the perceptual content, *i.e.*, *what* we perceive, may vary considerably while the sensory stimuli remain relatively constant. For example, the disk of the full moon looks different as we see in it now the face of the friendly 'man' or the profile of the lovely 'lady.' Similar and even more marked changes occur in those puzzle-pictures which at first view present merely a confused mass of lines and blotches, but which reveal to a more persistent scrutiny a deer, a face, or what not. Once the hidden object flashes into view, it is often wholly beyond one's power to see the picture as the mere confused mass it formerly appeared to be.

The principles by which perceptions are individuated and classified are not to be deduced from any mere likenesses and differences in stimuli received. It is not that the specific character of the stimulus does not count, but it counts only as a factor or element in a functional system.

To perceive something is not to respond to it in any particular way. It is rather to take an attitude of readiness to respond in some way not fully determined. It may be said that the capacity for perception, *i.e.*, for a cognitive awareness of the object, is the capacity for postponing response and thus for the selection of alternative possible responses to a relatively specific stimulus. The distinctive characteristic of the stimulus perceived, as contrasted with the stimulus emotionally felt, is the indirectness and complexity of its relation to response. We may generalize the relation of cognitive awareness to affection thus: In so far as a stimulus is calling into play a specific type of response, belonging to a

single genetic and functional system, it possesses the affective quality experienced in emotion; in so far as the stimulus calls into play an attentive postponement of response, it arouses cognitive awareness and possesses perceptual quality.

Now it is obvious, if this generalization holds, that cognition and affection are not antagonistic to each other, or mutually exclusive. They are, on the contrary, correlative moments in behavior, and as such clearly distinguishable. An emotion is never felt except in conjunction with some perception. One may be all charged, so to speak, with irritation or timorousness and just ready to be angry or to be afraid on the slightest provocation; but the anger or fear when it comes centers about some perceived object or event. In order to be angry one must be angry at something. To be angry at this thing is to assume an attitude of attack or menace, to be 'set' for destructive action. The particular form which this anger-attitude is to take, however, is variable. It remains to be determined, and progressively determined, by the exigencies of the occasion. The angry dog is charged with hostile intent; he is 'set' for growing and snarling, for leaping and biting; but whether he growls *or* leaps, just when he bites, and where—all this is determined by the acts and position of his adversary, *i.e.*, by the *perceived* features of the situation. It is just the relative indeterminateness and the variability of the anger-response that necessitates its dependence on the determining action of perception.

Each animal organism is endowed with inherited modes of response congenitally organized more or less completely. Thus, for example, a member of the cat family will exhibit very early the attitudes and movements characteristic of the pursuit and attack of prey. At first these are brought out by a variety of stimuli, often in a ridiculously inappropriate fashion. Even when the exciting stimulus is a natural object of prey, the various elements of the total response are badly coördinated with a view to successful capture. The stalking-period is too short, the grass is too obviously stirred, the spring is premature, and from the wrong position, etc. But gradually the function becomes perfected. If the prey is

not in a suitable position, the stalking is postponed, or a detour is made. A dozen circumstances serve to retard or to hasten, to modify and vary, the various stages of the pursuit. At any point it may be abandoned altogether, or taken up with a fresh orientation. Moreover the whole mode of procedure is varied according to the kind of prey hunted. Now this development and perfecting of the hunting-response is conditioned by a development of perception in the animal. At first, when the abortive reaction is set off almost regardless of circumstances, such perception as occurs is of the vaguest and simplest. Perceptual and affective qualities are scarcely differentiated. Even the prey itself is not distinctly perceived until the response called out is adapted both to the kind and to the special circumstances. Its discrimination as prey depends on the discrimination of other objects and items as definitely determinative factors in the total situation. For an object or item to be perceived it must have acquired the power to function as an element or factor in the total situation. It must be a conditional determinant of response, in a more or less definite and systematic way.

Perhaps the grasping child will serve to illustrate more fully this distinction. When the grasping period begins, the baby reaches out both arms in an aimless jerky fashion. He is 'set' for grasping, and almost any visual stimulus which arouses fixation suffices to initiate this response. At this stage the baby cannot safely be said to see the exciting 'ball' or 'rattle' or 'face' or 'light.' He cannot be said to see any 'thing' whatsoever, for the simple reason that he gives no evidence in the way of discriminatory behavior. All these stimuli are, however, undoubtedly exciting and attractive, although the words carry too definite a meaning properly to describe the formless content of the baby's experience. But discrimination rapidly develops. Not only is there preferential selection among the things grasped, but the movements of body, arm, and hand are adjusted to position and distance of the thing grasped for. As this coördination is consummated, and the hands reach the object of their search, they fumble it over and bring it to the mouth. So gradually

is brought about that complex adaptation of grasping and manipulating movements, not only to position and distance, but also to size, shape, and even texture. Not until these complicated systems of response are organized does perception of the thing as object having position and solidity, shape and size, come into being.

Let us note more closely the relation of the perceived property of distance to the behavior of the grasping child. What sets the child to grasping at all at the object is the vaguely yet specifically attractive look of it. But the nice adjustment of leaning just so far in such a direction, and stretching out the arm just so far, and moving the wrist and fingers just so far, is controlled by the pattern of the sensory excitation from retina and eye-musculature. There is no simple one-to-one correlation of sensory excitation with motor reaction, in which each variation in excitation calls out its own specific variation in response. On the contrary since a given distance and position may be represented by a number of different sensory complexes, these functions are equivalent. That is, each and every such complex serves as stimulus to that coördinated sequence of tensions and flexures which results in the fingers' touching the object so placed with reference to the child. But this sequence of movements may vary considerably. One may bend the body farther and stretch the arm commensurately less; or, if one bends first to one side, one must compensate by stretching the arm differently. As bodily skill develops, one learns to execute a multitude of combinations of movements, each of which results in bringing the fingers in contact with an object in the given position. The perception of position, then, is conditioned by the development of a complicated functional system, the characteristic feature of which is the correlation of a variety of equivalent patterns of sensory complexes with a variety of equivalent patterns of motor complexes.

The account just given is of course merely schematic. The interweaving of sensory and motor patterns is enormously more intricate than has been indicated. Perception of spatial position and distance of an object involves not merely

the capacity for reaching it with the hand, but for walking around it, avoiding it in movements directed toward other objects, and, not least important, for dealing with it indirectly by means of other objects in a thousand ways.

The perception of spatial properties is of course peculiarly rich in the wealth of definite and detailed correlations by which it is conditioned. But a similar type of schema underlies all perception. The concrete perception of any object is made up by a complex of sensory patterns of position, shape, size, texture, etc., each of which has its own subordinate correlations with motor patterns, and which possesses in consequence a certain degree of what may be called functional independence; that is, it may appear as a factor in other total complexes having the same potential value as a conditional determinant of response.

What is true of the perceptual properties which belong to the object is true of the perceived object as an individual totality. It too is represented by a great variety of sensory patterns, corresponding to the view of it in different positions and illuminations in different states. These are all united, in spite of their diversity, by their functional equivalence. Thus any view of a familiar plaything may serve as well as any other view of it to initiate the type of play-response appropriate to the particular object, although the detail of the movements of walking toward it or climbing for it will vary with its position on table or on high shelf. It is, indeed, the functional equivalence of the varying sensory complexes aroused by an object that forms the basis of the recognition of it as *the* object—ball, or knife, or mother—which it is.

The parts which emotion and perception play in behavior we have seen to be characteristically different. The distinctive peculiarities of the content belonging to each of these functions correspond to the part played by each. The affective qualities of things represent the immediate and direct functional value which the things possessing them bear to the animal, and they control specific type-reactions directed to the thing thus qualified. The perceptual qualities

of things represent indirect and conditional functional values. They control the detail of activities, whose general form is dictated by some type of affection. Their capacity for this control of detail is conditioned upon the development of complicated systems of nervous activity, in which groups of differing sensory patterns have like functional relations with corresponding groups of differing motor patterns. Perceptual qualities and properties are thus conditional factors, possessing, because of their conditionality and systematic interrelationship, functional independence. It is the functional independence of the perceptual quality that gives it its attentive clearness, its qualitative distinctness. It is the wealth and variety of its functional relationships which makes it a fit subject for description and comparison. The featurelessness of the affective quality, on the other hand, its indescribability, is due to the very simplicity of its relation to the organism. Because it is relatively unconditional in its control of behavior, and is not a factor having a determinate place in a vast system of nervous organization, it eludes attentive scrutiny. Because to experience it at all is to be already committed to a specific type of response, it can only be felt, and not cognized.

As emotion and perception are correlative to each other, so in a more general sense do affection and cognition play complementary parts in the economy of life. It is our feelings that furnish the springs of action; it is our intelligence that guides and directs that action. By virtue of their affective qualities, objects and fellow-beings, situations and events become ends of action; for affective qualities represent the direct functional relations which things bear to us, their power to work us weal or woe, to satisfy our needs or thwart our activities. They arouse us; they fill us with longing or with aversion; they beckon us on or warn us away. They form as it were the foci of the larger curves into which the course of living falls, the points of reference for the determination of general direction. The properties and relations of things, on the contrary, which our intelligence discovers, and which are constitutive of them as entities making up an

interrelated but independent world, have no direct and simple relation to our needs and capacities. The understood causal relation of events, like the perceived shape of objects, leaves us cold. It may have an interest for us, but it is rather as a means than as an end. It represents a sort of condensed expression for a multitude of definite conditionalities. It says, as it were: If you will gain (or avoid) one object, you must deal thus and so with another. If the affective qualities determine the larger curves and the greater changes of direction, it is the cognized properties and relations that account for the complicated twistings and turnings and interlacings which mark our course.

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DARK-ADAPTATION WITH ESPECIAL REFERENCE TO THE PROBLEMS OF NIGHT-FLYING

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Introductory

This work was undertaken with a view to designing a method whereby the visual fitness of the aviator for night-flying might be tested. His absolute sensitiveness for light is one datum sought. Another is his rate of recovery after the relative blinding following exposure to light for short periods.

Researches heretofore made on dark-adaptation have shown that in the course of an hour spent in the dark the sensitiveness of vision for light increases gradually, and may in the course of the hour increase several thousandfold over its initial value;[1] or less according to the duration and the intensity of the light to which the eyes have been previously exposed;[2] until a point is reached beyond which no further change is to be found.

The present work contemplated exposing the eyes of the observer to light of a standard intensity for certain measured periods of time, and subsequently investigating the course of his light sensitivity. Since from what has just been said it appears that exposure of the eyes to light prior to the time the observer comes under investigation may produce effects which do not completely wear off in less than an hour, it was necessary, before beginning the experiment proper, to make sure that the observer had reached a standard and reproduc-

[1] Piper, 'Ueber Dunkeladaptation,' *Zeitsch. f. Psychologie u. Physiologie d. Sinnesorgane*, **31**. See also Lohmann, 'Disturbances of the Visual Functions,' Blakistons, Philadelphia, 1914, Chapter V.

[2] Nicola, *Zentralblatt f. Physiologie*, **21**, vide Lohmann, Disturbances of the Visual Functions, 1914, p. 71; and Rabinowitsch, *Zeitsch. f. Augenhk.*, **19**.

ible condition. The obvious way to accomplish this was to measure his light sensitivity from time to time, as he remained in the dark, until a stage was reached beyond which no further increase was noted. It was then assumed that his vision had become completely dark-adapted, and was in a state which could, for the individual and for experimental purposes, be taken as a standard. The actual experiment began after this point had been reached.

Apparatus and Methods

The test of light-sensitiveness is, in the first instance, the photometric brightness of a surface which is just visible with certainty. The instrument by which such a dimly-bright surface is maintained and its brightness known is the adaptometer. The particular one used here was designed on the fundamental principle proposed by Nagel,[1] with certain technical modifications. It consists of a box, made of ½-inch white pine, 29 inches (73.6 cm.) long, 8 inches (20.3 cm.) wide and 7¼ inches (18.4 cm.) high, inside measurements. A ½-inch cross-partition divides its length into two compartments 11 inches and 17½ inches (27.9 and 44.4 cm.) long (Fig. 1, *A*). At the outer end of the longer one of these compartments a milk glass, *MG*, 5 inches (12.7 cm.) square is attached to cover a somewhat smaller opening. The test-pattern is projected upon the inside of this glass by an optical arrangement which is in effect a miniature stereopticon, consisting of a projecting lens, *P*, supported in an opening in the cross-partition; and within the smaller compartment a condensing lens, *C*, and an electric lamp, *L*, together with a 'slide,' S_1. This last is a thin slip of brass in which openings are cut (Fig. 1, *B*), the image of the openings projected on the translucent screen, *MG*, being the test-pattern viewed by the subject.

The lamp is a 12 c.p. tungsten-filament auto headlight lamp, rated at 6 to 8 volts, 2 amperes, with a 1½-inch spherical bulb. It was actually operated at 1.75 amperes to avoid too rapid deterioration. The current was supplied by a small

[1] *Zeitsch. f. Augenhk.*, 17, 3.

storage battery and controlled by rheostat and ammeter. The lenses are 1½-inch ophthalmologists' trial lenses removed from their rims. *C* is of 18 diopters, and *P* of 13 diopters' power. The first focuses the image of the lamp filament upon a slit, S_2 (Fig. 1, *A*), the distances being such, that a reduction in size as 5:3 takes place. That is, *LC* is 14.8 cm. and CS′ 8.9 cm. approximately. The slit is ½ mm. wide by 10 mm. high. The amount of light entering the slit is reduced

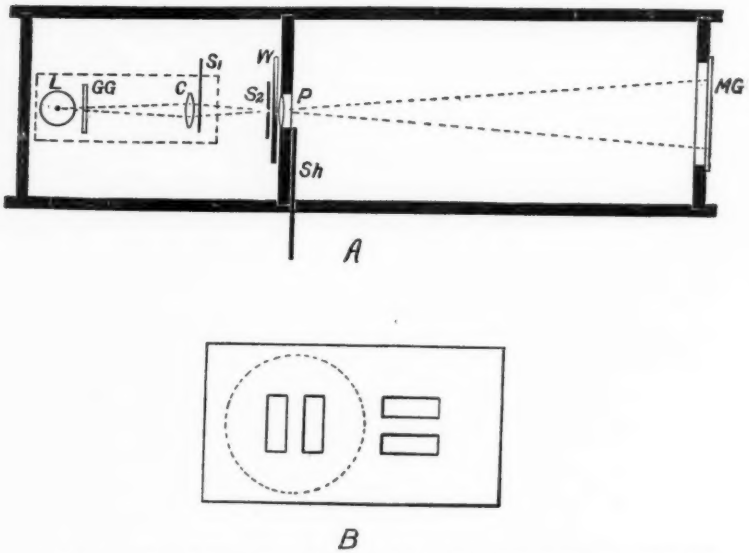

FIG. 1. The adaptometer. *A*, plan of the instrument in section. See text for explanation. *B*, the slide, showing the test-pattern in the two positions. The face of the projection lens is indicated, for one position of the slide, by the dotted circle.

by a ground glass, *GG*, and, by way of adjustment, may be further decreased by moving the glass farther from the lamp. The last adjustments as to the relative positions of these parts were made without the ground glass in place so that the image of the slide, S_1, was accurately focused upon the milk glass, *MG*.[1] It was then determined just where the

[1] The distances determining the size of the test-pattern are S_1–*P* 9.2 cm. and *P*–*MG* 46.2 cm. approximately. The magnification is here as 1 : 5.

image of the lamp-filament fell and the slit was permanently placed at just the same distance from the cross-partition. This was accomplished by mounting the lamp, condensing lens and slider (L, C, S_1) in their proper relative positions permanently on a small table which could be shifted about slightly and then clamped.

The finer changes in the brightness of the test pattern, necessary during the experimental procedure, were brought about by an absorbing wedge (W), of which the light transmission varies by indefinite gradations in the ratio of 29,100 : 1 between its extreme positions 100 mm. apart. This is mounted immediately behind the slit, between it and the projecting lens, and is provided with a millimeter scale and a mechanism by which it may be shifted from the outside of the box. It was found by photometric measurement that the brightness of the test-pattern was 0.0272 candles per square meter when the wedge was set at zero of the scale. In such a wedge the change in the amount of light transmitted

TABLE I

THE PHOTOMETRIC BRIGHTNESS OF THE TEST PATTERN, IN CANDLES PER SQUARE METER, FOR EACH CENTIMETER OF THE ADAPTOMETER SCALE. THE COLOGARITHM OF THE SAME WITH THE DIFFERENCE FOR EACH MILLIMETER DIVISION, FROM 0 TO 10.

Candles per Sq. Meter	Scale, Cm.	Colog. C. P. Sq. M.	Proportional Parts	
			Mm.	Diff.
272×10^{-4}	0	1.566	0	0.000
973×10^{-5}	1	2.012	1	0.045
348	2	2.458	2	0.089
102	3	2.905	3	0.134
446×10^{-6}	4	3.351	4	0.179
159	5	3.798	5	0.223
570×10^{-7}	6	4.244	6	0.268
204	7	4.690	7	0.312
730×10^{-8}	8	5.137	8	0.357
261	9	5.583	9	0.402
935×10^{-9}	10	6.029	10	0.446

is in a certain constant ratio for each equal linear shift of the wedge. In the wedge used each shift of 10 mm. from 0 toward 100 mm. was found to change the amount of light transmitted by the factor 1/2.795 or 0.358. The relation between scale reading and brightness is best worked out by logarithms and is as indicated in Table I. At 0 mm. the brightness is 0.0272

c. per sq. m., logarithm −1.5656. The logarithm diminishes by 0.44638 for each cm., or by 4.4638 for 10 cm. In the table the negative signs are dropped, hence the figures are cologarithms from which brightness may be directly found. As they stand in the table the logarithms may be taken as expressing the grade of sensitivity corresponding to the respective scale-readings.[1]

The test-pattern itself is in form a pair of bars of such dimensions that they represent the remainder of a square after its middle third is removed. Two such patterns were cut in the slide (Fig. 1, *B*) in such a way that the image might be shown in the horizontal or in the vertical position. Each opening in the slide is 15 x 5 mm. and the strip left between the two, in each pair, is 5 mm. wide.

Directly above the test-pattern and on a level with the eyes of the observer is a fixation-point (Fig. 2), consisting of a 4- to 6-volt, tungsten filament, tail-light lamp operated on one dry cell. The light from the lamp, operated so much below its rated voltage, was dim and reddish and it was further dimmed by coloring the lamp with red dip and by interposing layers of paper between it and a diaphragm (with an opening of about 6 mm. diameter) which is directly in front of it. The fixation point was kept just bright enough to be located in the dark. Its distance from the eyes of the observer was 52 cm. The center of the test-pattern is 12 cm. below the fixation point, and therefore 13 degrees below the center of the visual field. The test-pattern subtended about 8 degrees both horizontally and vertically in the visual field. A sliding shutter (*Sh*, Fig. 1, *A*) was arranged to darken the test-pattern completely except when actual observations were being made.

During the progress of the experiments in the dark all light, except that from the adaptometer, that from the fixation point, and that from a small reading lamp, was excluded from the room. This last is a 4- to 6-volt tail-light lamp, operated on a single dry cell. It was used in recording the

[1] This mode of expressing the grade of dark-adaptation is quantitatively different from that proposed by Best (*Arch. f. Ophthal.*, **76**, pp. 146–58) but the same in mathematical principle.

results and was always kept well shaded. Possible stray light from this and other sources was kept from the observer by a black felt curtain.

Procedure

The subject was seated in darkness before the adaptometer with his forehead just touching a fixed support, and fixated the red fixation-point (Fig. 2). The shutter was opened for approximately one second and he was asked to state whether he saw the test-pattern, and if so, in what position. By repeated trials the point on the scale was found at which he was just able to report the position of the test-pattern correctly. The time was immediately taken and entered in the record along with the scale reading. This was repeated at intervals of about five minutes, the subject resting in the mean time. Usually the subjects had been spending the last hour or two, before the room was darkened, in some part of the laboratory and as a consequence the time required to reach a constant threshold was less than an hour. In general, at the end of twenty or thirty minutes it was found that two or three readings had been taken which were in agreement to within the limits of precision of the method.

When this point was reached a white screen was placed before the eyes of the subject, leaning against the front of the adaptometer at a definite inclination; and the center light of the room was turned on. The subject was instructed to maintain his position and direct his eyes toward the center of the screen. In preparation for what was to follow, the test stimulus, set at a certain point, was exposed by drawing the shutter. Five minutes from the time the light was turned on the screen was quickly removed and the light turned off after an interval of perhaps one or two seconds in which the observer could locate the fixation point. He remained at this fixation until the test stimulus, at first invisible owing to the five minutes blinding, became visible to him. The time required for this to take place was noted. Subsequently readings were taken as before, but somewhat more frequently, until the former absolute threshold was again reached.

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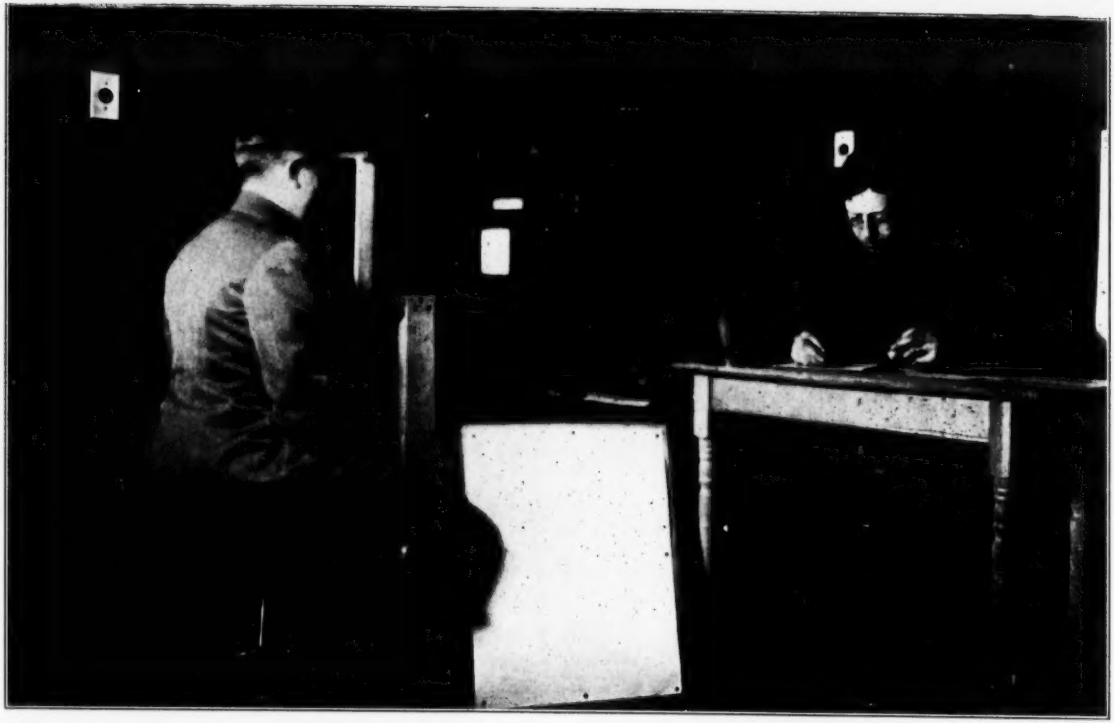

FIG. 2. General view of the adaptometer, the observer (to the left) and the experimenter. The test-pattern appears on the square white surface on the end of the instrument and is not visible except in the dark. Above this is the fixation point with the dry cell attached. The white screen used for the purpose of 'blinding' the subject is below in the foreground. The experimenter holds the reading light in his left hand.

Finally, the white screen was replaced and the procedure of the last paragraph repeated with fifteen seconds exposure to the white screen, in an exactly similar way. From the time the subject entered the room until the end of this third portion of the experiment the whole procedure occupied from an hour to an hour and a quarter, according to the speed of the subject in recovering his absolute threshold.

The screen used for 'blinding' the subject was a sheet of white blotting paper 24 by 19 inches, mounted on a light frame. Its angle of inclination and distance from the eyes were such that it subtended, at the eyes, an angle of 67 degrees vertically and 70 degrees horizontally in respective planes through its center. Its lower half was nearer the observer, consequently including a larger angle, easily including that part of the visual field occupied by the test-stimulus and much more in every direction. The photometric brightness of this screen averaged 13 candles per square meter by actual measurement.

Results

The various values for sensitiveness were plotted, each against the time at which it was obtained. Thus each experiment yielded three curves as in Fig. 3. The first of the three began with the state of adaptation in which the subject happened to be and was carried on until his absolute threshold had been reached. This was taken as one datum in his case.

The second curve represents his recovery after five minutes blinding[1] by a surface of standard extent and brightness. Here the question was rather his rate of return to dark adaptation than the ultimate point. The first datum here, in the chronological course of the experiment, was the time required to see an initial stimulus, already exposed when the room was darkened, as his dark adaptation progressed and the sensitivity of his vision grew sufficient to take account of it. At this stage the increase in sensitivity is

[1] The word 'blinding' is used here for want of a better and equally short expression, meaning only that effect, due to which the subject is relatively and temporarily blind to stimuli of the very low intensities considered.

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rapid, for which reason the technic just described was made use of. The method was not satisfactory in that the whole result depended upon a single judgment of the observer. If for any reason he failed in this, as happened on certain occasions, there was no way of repeating without undue expenditure of time. The results so obtained are nevertheless given and are not, on the whole, without significance.

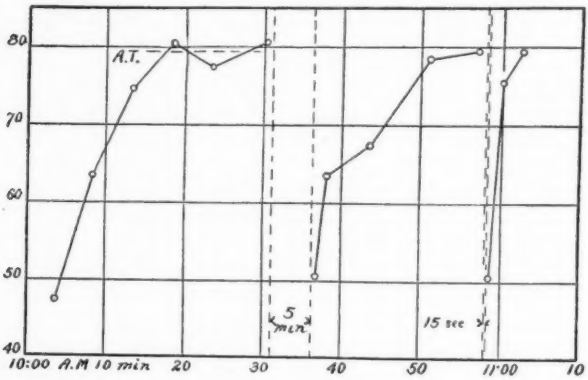

FIG. 3. Specimen plot of one experiment. The first curve was taken without preparation. In this case the mean of the last three points (79.5 mm.) was taken as the absolute threshold, and its location on the plot is indicated by the horizontal interrupted line. The two blinding periods are indicated by the vertical interrupted lines. The return of both curves to the exact value of the mean absolute threshold is simply coincidence; usually there is some discrepancy.

It could not, of course, be predicted when the subject would reach a given degree of sensitiveness. Every exposure to the test stimulus seemed to blind the subject slightly, especially in the later and more complete stages of dark adaptation, where the disturbance might amount to a number of millimeters on the scale. When, after a waiting interval, the right point was hit upon, rather by accident, the stimulus might be seen at a very low value; whereas after several trials by the trial and error method a new and larger value (lower on the scale) would be found; the subject in the mean time being unable to repeat the initial observation. It would seem then, that the first point, taken with the stimulus

set and exposed on increasing dark adaptation immediately after darkening the room, is not strictly comparable with the later observations, taken by a trial and error (perhaps better called a 'bracketing') method, with the stimulus darkened in the intervals. In general a rapid method had to be used, since the quantity measured was, for the most part, continuously changing; and a different and more rapid method had to be used to get an index of the initial rapid rise within the first minute or so.

A study of all the plotted curves led to the selection, for the purpose of discussion, of a comparatively few data. Some of these rest upon an arbitrary basis, but all the possibilities are involved.

Those so selected are:

1. The absolute threshold.

2. (*a*) The time required to reach an arbitrary, rather low degree of sensitiveness, obtained by noting the instant that the test stimulus appears to emerge from the darkness.

(*b*) The time required to reach an arbitrary level (70 mm. on the scale) obtained by linear interpolation from the curve of rise.

(*c*) The time required for the individual to reach a point on the scale 15 mm. short of his own absolute threshold.

The data indicated under (2) comprise two parallel sets, the one following five minutes blinding, the other following 15 seconds. It will be noted that while (*a*) and (*b*) under (2) are data relative to fixed stimuli those under (*c*) are relative to the subject's own standard and will indicate his individual capacity, rather his individual rate of recovery than his competitive performance under given external conditions. The data just described are given in Table II. The arrangement of the observers here in the upper block of the table is approximately in the order of magnitude of the absolute threshold, the third column giving the same in terms of the adaptometer scale, the fourth giving the corresponding logarithmic sensitivity (the cologarithm of the brightness in candles per square meter). The fifth gives the brightness itself in hundred-millionths. The first value in this column is thus 0.00000134 candles per square meter.

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TABLE II

THE RESULTS OF THE DARK ADAPTATION EXPERIMENTS

The absolute threshold is stated (1) in terms of the scale reading, (2) as the cologarithm of the brightness of the test-pattern and (3) as that brightness itself in hundred millionths of one candle per square meter.

Under 'AT–15' is given the time of return of the individual to a threshold 15 mm. below his own absolute threshold on the scale (which is photometrically 4.7 times as bright).

Similarly, under '70 mm.' and '50 mm.,' the times of return to these respective points on the scale, as described in the text. These two points are respectively of 0.0000204 and 0.000159 candles per square meter brightness.

The lower block of the table gives the comparative results of repetition of the same experiment upon each of three observers, except in the case of W, in whose case the order was reversed and 15 seconds blinding given first.

The same was the fact in the case of observer M, in the upper block of the table.

In the last column the asterisk (*) indicates that the course of adaptation was too rapid to permit of taking the time as the first point (50 mm.±) was reached.

Date	Obs.	Absolute Threshold			AT–15 Mm.		70 Mm.		50 Mm. ±	
		Scale Mm.	C. P. Sq. M. Colog.	C. P. Sq. M. × 10^8	Sec. After Blinding		Sec. After Blinding		Sec. After Blinding	
					5 Min.	15 Sec.	5 Min.	15 Sec.	5 Min.	15 Sec.
Nov. 7, '18	R	96.5	5.873	134	300	106	151	76	30	12
Dec. 20, '18	Do	91.5	5.650	224	385	84	79	66	37	10
Jan. 6, '19	O	88.5	5.516	305	315	82	213	72	48	15
Jan. 7, '19	Sh	88.0	5.494	321	291	—	236	—	48	—
Jan. 17, '19	G	88.0	5.494	321	160	76	142	66	30	5
Oct. 31, '18	Ho	87.0	5.449	356	140	—	127	—	10	—
Nov. 4, '18	Si	89.0	5.539	289	86	43	62	36	20	10
Jan. 17, '19	Co	86.0	5.405	394	204	87	170	83	43	12
Jan. 18, '19	W	83.5	5.293	509	281	95	307	99	50	13
Jan. 8, '19	B	81.5	5.204	625	300	63	405	75	62	5
Jan. 3, '19	L	82.5	5.248	565	135	51	151	56	32	16
Jan. 17, '19	Du	81.0	5.182	658	129	70	291	87	25	8
Nov. 13, '18	Hn	79.5	5.114	769	192	70	542	87	30	25
Nov. 26, '18	M	77.0	5.002	995	212	44	390	60	20	*
Jan. 14, '19	Cr	77.0	5.002	995	86	56	230	82	25	20
Mean.....	.....	85.1	5.364	497	214	71	233	73	34	12.6
M. V.....	.....	4.5	.201	218	78	16	103	12	11	4.4
Nov. 7, '18	R	96.5	5.873	134	300	106	151	76	30	12
Jan. 15, '19	R	92.0	5.672	213	265	98	148	74	20	10
Oct. 31, '18	Ho	87.0	5.449	356	140	—	127	—	10	—
Nov. 1, '18	Ho	87.5	5.471	338	177	—	117	—	15	—
Nov. 9, '18	W	80.5	5.159	693	259	44	662	52	55	*
Jan. 18, '19	W	83.5	5.293	509	281	95	307	99	50	13

It will be seen that the variations here are quite large, 134 and 995 hundred-millionths being the extremes, which

are as 1 to 7.4. On this account it seemed more rational to average these logarithmically, thus arriving at the geometric mean as has been done in columns three and four, than to average the numerical values of column five. The following figures show the results of the two methods comparatively:

	Geometric Mean		Arithmetic Mean
	Cologarithms	Numerics × 10^8	
Mean	− 5.364	433	497
M. V.	∓ 0.201	—	± 218
Mean + m. v.	− 5.163	687	715
Mean − m. v.	− 5.565	272	279

The arithmetic method gives a larger result with a range of variation only slightly broader.

The remainder of the table consists of the various data just enumerated.

Discussion

The meaning of the results will perhaps be more readily apprehended from Table III. Here the results in each

Table III

Similar to Table II (q.v.) Giving Ratings Instead of Experimental Values.

The ratings are 1 to 5 in order of superiority, 3 indicating the average class.

Date	Obs.	AT	AT–15 5 Min.	AT–15 15 Sec.	70 Mm. 5 Min.	70 Mm. 15 Sec.	50 Mm. 5 Min.	50 Mm. 15 Sec.
Nov. 7, '18	R	1	5	5	2	3	2	3
Dec. 20, '18	Do	1	5	4	1	2	3	2
Jan. 6, '19	O	2	5	4	3	3	5	4
Jan. 7, '19	Sh	2	4	–	3	–	5	–
Jan. 17, '19	G	2	2	3	2	2	2	1
Oct. 31, '18	Ho	2	2	–	2	–	1	–
Nov. 4, '18	Si	2	1	1	1	1	1	2
Jan. 17, '19	Co	3	3	4	2	4	4	3
Jan. 18, '19	W	4	4	5	4	5	5	3
Jan. 8, '19	B	4	5	2	5	3	5	1
Jan. 3, '19	L	4	2	1	2	1	3	4
Jan. 17, '19	Du	4	1	3	4	5	2	2
Jan. 13, '19	Hn	5	3	3	5	5	2	5
Nov. 26, '18	M	5	3	1	5	2	1	*
Jan. 14, '19	Cr	5	1	2	3	4	2	5
Nov. 7, '18	R	1	5	5	2	3	2	3
Jan. 15, '19	R	1	4	5	2	3	1	2
Oct. 31, '18	Ho	2	2	–	2	–	1	–
Nov. 1, '18	Ho	2	2	–	1	–	1	–
Nov. 9, '18	W	4	4	1	5	1	5	*
Jan. 18, '19	W	3	4	5	4	5	5	3

column in the first section of Table II. have been 'rated' in five classes, according to the theory of probability, in such a way that out of an indefinitely large number of cases, of which these fifteen may be considered a sample, one fifth showing the most favorable values would rate 1, the next fifth 2, and so on, the lowest fifth rating 5. Thus 3 would be the rating of the intermediate fifth of the whole number, the group of one fifth falling nearest the average.

This was done independently for each column of results (excepting the actual brightness, column 5, Table II.) and the ratings are given in Table III. It was found that those rating higher as to absolute threshold were, on the whole, slower to return to within 15 mm. of that point ('AT–15 mm.'). Accordingly, the arrangement of the observers in the table was based in these two considerations and the same arrangement followed in constructing Table II.

This fact, upon a few moments reflection, is not surprising. The observer who has a very low absolute threshold is taken farther from it, so to speak, in adapting to the standard blinding brightness and might be expected, other considerations equalized, to be longer returning to it, or to a point remote from it by an equal interval, and is not necessarily slower in getting back to a given threshold. For example L, rating 4 as to absolute threshold, rates on the whole almost, if not quite, as well as R or Do in point of his return to 70 or to 50 mm.

It is fortunate that Table III exhibits in four individual cases four types of adaptation. These are: high and low grade adaptation, each with rapid and slow recovery as indicated:

	Absolute Sensitivity	
	High	Low
Quick Recovery	Si 2, (1,1)	Cr 5, (1,2)
Slow Recovery	R 1, (5,5)	W 4, (4,5)

The plotted curves for these are reproduced in Fig. 4. The curves for the other observers, drawn from the observations following the 5 minutes blinding, fall within the limits of these, except for one or two which intertwine with one of the extremes appearing in the figure, and except for

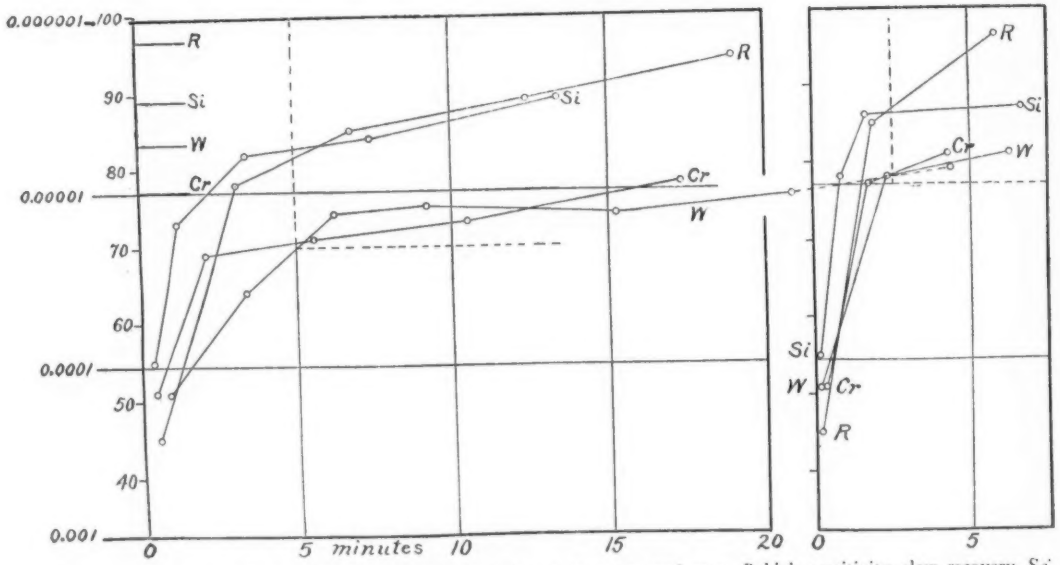

FIG. 4. Four cases showing typical courses of adaptation as to extent and rate: *R*, high sensitivity, slow recovery, *Si*, same, rapid recovery; *Cr*, low sensitivity, rapid recovery, *W*, same, slow recovery.

On the left, after 5 minutes blinding, on the right after 15 seconds blinding.

The absolute thresholds, previously taken, are indicated near the upper left angle of the figure.

two special cases (which will be discussed later) in which the curve distinctly drops below the lowest one of the four.

It will be noted by comparison of the curves of R and Cr showing respectively high absolute sensitivity with slow recovery and the reverse, that Cr is somewhat more quick than R in reaching a given simulus, up to the neighborhood of 70 mm. The case is somewhat different if we compare the curves of R and Cr, resulting after 15 seconds blinding, as they appear in the right-hand portion of the plot. Here Cr appears to be the slower and this would, in all probability, be shown more definitely if the curves could have been drawn from more abundant data and more in conformity with the course of the absolute threshold instead of being, as they are, simply broken lines joining rather widely separated points.

Examination of all the curves points to a possibility of dividing the course of adaptation, for the technical purpose of studying and testing individuals, into two portions: the early abrupt rise out of the relatively blinded state, and the late, slow approach to the absolute threshold. The tentative limits of these are indicated in the plots (Fig. 4) by the dotted lines—in the case of 5 minutes blinding all observations after five minutes and above 70 mm. on the scale (within the dotted right angle) being classed in the latter portion of the curve; the corresponding limits being 2½ minutes and 76 mm. in the case of 15 seconds blinding. All this, of course, is tentative and is to be taken in connection with what is subsequently to be said in regard to the practical phase of the subject and the photometric conditions which the vision of the aviator has to meet in actual flying.

Examination of Table III., columns headed 70, shows that the first seven observers having the lowest absolute threshold return to the point 70 on the scale in better time, on the whole, than the average, and the last seven observers in slower time. The point 70 mm. therefore reflects on the whole rather the absolute threshold than the individual's speed of recovery.[1]

[1] The variations in the average times of recovery under the different experimental conditions, to be expected concomitantly with different degrees of absolute

Under the head 50 mm. the distribution of ratings is seen to be more even, regardless of the two individual factors. These latter results (time to reach 50 mm.) are however less complete and less trustworthy than the former. It can only be said that a selected point on the scale, taken as the sole basis of rating and reflecting on the average neither the absolute threshold nor the individual rate of recovery (that is, giving equal weight to both) would have to be chosen somewhat below 70 mm. on the present scale.

The degree of uniformity with which results may be reproduced in successive experiments is indicated by the figures in the lower blocks of Tables II. and III. In the cases of Ho and R, the ratings are either identical or, in some cases, one stage apart. The wide difference in the case of *W* is accounted for. In the experiment upon him of November 9 the usual order of experimentation was reversed in that 15 seconds blinding was carried out first, then 5 minutes. The outstanding feature of the result is that in the case of November 9, the subject rates high after the 15 seconds period and low after the 5 minutes, whereas on January 18 with the usual order of experimentation his ratings for the two cases are more consonant. The like is true, less markedly, in the case of M (upper portion of tables), upon whom also the experimental order was reversed. He shows, especially under the head 70 mm., a disparity of rating for the two

sensitivity, were worked out statistically from the data of Table II. In the following, *m* is the number of seconds difference in the average recovery-time to be expected with a difference of absolute sensitivity corresponding to 1 mm. scale, *i.e.*, as 1 : 1.108, while opposite *r* is given the respective coefficient of correlation followed by its probable error.

Recovery to:		After a blinding period of: 5 minutes	15 seconds
AT–15 mm. or	*m*	7.45 sec. per mm.	2.05 sec. per mm.
AT × 4.7	*r*	0.443 ± 0.140	0.611 ± 0.117
70 mm., or	*m*	− 16.4 sec. per mm.	− 0.68 sec. per mm.
204×10^{-7} c.p.sq.m.	*r*	0.671 ± 0.099	0.244 ± 0.176

It will be noticed that the time to recover to 70 mm. after 15 seconds blinding is least of all governed by the absolute sensitivity. The rate of variation is − 0.68 seconds per millimeter of scale and the coefficient of correlation is not much greater than its probable error.

different periods of blinding which is unusual, and in every case he rates higher after the 15 seconds blinding than after 5 minutes. It is also true that these two (W and M) show in the same experiments (after 5 minutes blinding where this was preceded by the 15 seconds period) curves which drop below and somewhat outside of the limits indicated by the four types of Fig. 4. This would indicate that in these two cases, at least, the return after the shorter blinding period is more rapid owing to its not having been more or less immediately preceded by an experimental blinding period, while, *per contra*, the rise after a longer blinding period is delayed by reason of a foregoing blinding. This with reference to the general results of the usual order of experimentation as a standard. A further conclusion is that the general result in the bulk of the cases is influenced in a similar way, and the general rate of recovery after the short blinding period is delayed, owing to a residual effect of the prior blinding. If this be true the rise after 15 seconds blinding should, under equal preceding conditions, ensue with greater relative speed than the average results would indicate.

It is possible that the sudden onset of the rather bright light, after complete dark adaptation, may, so to speak, surprise the visual apparatus into more profound changes than would be induced by the same exposure to light applied with gradual onset under similar conditions. Aside from the changes in the size of the pupil there are two anatomic factors undoubtedly concerned in dark and bright adaptation: the exhaustion and regeneration of the visual purple (or possibly other unknown photochemical substance); and the migration of the pigment of the hexagonal cells. This latter may be a protective device that acts fairly promptly, and has the effect of enclosing the retinal rods and by its own light-absorbing qualities reducing the amount of light absorbed by the individual rods. It is conceivable that a sudden flash of light might anticipate this action and produce a strong destruction of the photochemical material in a short time, before the pigment cells have had time to react, while with gradual onset of light the time is adequate

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for the pigment cells effectively to assume this protective function.

Some of the curves strongly suggest two factors playing a part in dark adaptation. In Fig. 5 one of these is shown together with a typical smooth curve. Any attempt to smooth out D's curve here would have to proceed on the assumption of large experimental errors at the second and

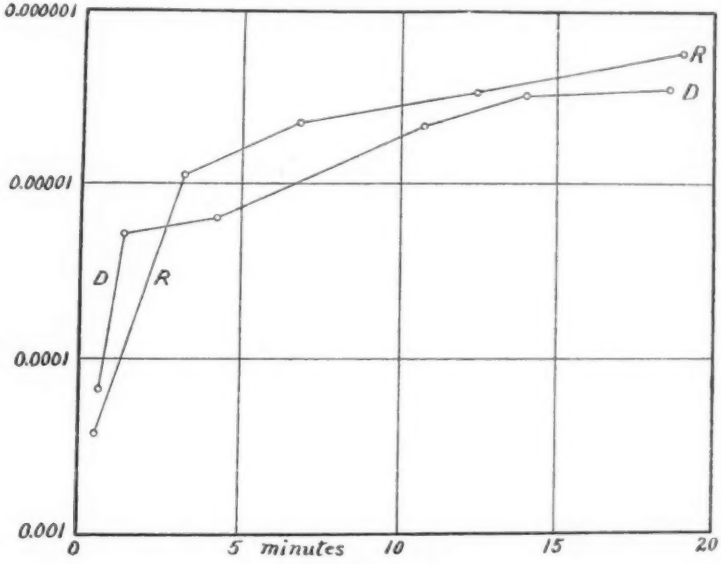

FIG. 5. Two types of adaptation curve. *R*, 'normal' or regular form. *D*, irregular form showing a halt within the first five minutes and subsequently a more rapid rise.

third stations; or else the results would have to be interpreted as arising from two more or less independent mechanisms one of which overtakes the other, in effect, at the end of about four minutes. Such terrace-like irregularities, which may be interpreted as a halt in the progress of dark-adaptation, are present in 14 out of a total of 52 adaptation curves taken, and are suggested in four others. The results obtained after five minutes blinding are plotted for all 15 observers in Fig. 6, to show the great variety of forms the curves may take.

It will be evident from the foregoing discussion of the experimental results that the time required for adaptation to progress to the point of visibility of any test-stimulus is a function of the individual's optimum and also of his rate of recovery from the effect of disturbing light; with one or the other of these of predominant effect according to the magnitude of the test-stimulus selected. No single rating derived from time and stimulus magnitude would necessarily be

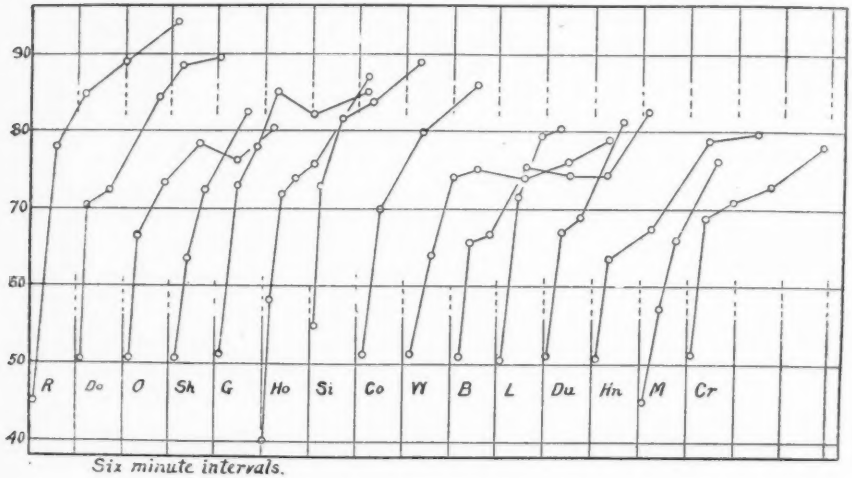

FIG. 6. The course of adaptation after 5 minutes blinding in 15 different subjects. The vertical line in each case is the zero ordinate for the corresponding curve, indicating the instant the blinding period came to an end and the dark-adaptation began. These ordinates are arbitrarily plotted six minutes apart.

valid as an index of the efficiency of the same individual with respect to stimuli of other magnitudes. Again, the ratings of two individuals, taken in this way, might, by the arbitrary selection of the test-stimulus, be so made as to place either one of the individuals above the other. Obviously, such a method of estimating the efficiency of night vision cannot be considered valid.

By way of outlining a method for testing night vision, there is little to be stated in detail until definite data are at

hand (1) as to exactly what, photometrically considered, the aviator must necessarily be able to see in night-flying, and (2) what transient light conditions he may meet which tend to make him blind relatively to such visual objects. The former might afford a basis for the rational selection of a test-stimulus, the latter a basis for standardizing the duration and intensity of the experimental blinding.

As far as is known to the writer, photometric measurements of the brightness of the sky, the earth's surface and the objects upon it have never been made under natural illumination at night. Such measurements would show whether the requirements of vision at night are more lenient than those demanded at the absolute threshold in the experimental dark room, or equally exacting; and whether the rate of recovery is more important, for practical purposes, than the value of the absolute threshold. In short, such data, taken in connection with data such as those of the present work, would show which portion of the adaptation curve is the more worthy of intensive study from the present viewpoint: the early, abrupt rise, out of the relatively blinded state; or the slow approach to the absolute threshold.

The Relation of Shade-perception to the Dark-Adaptation Results

In connection with the foregoing some experiments were undertaken in shade-perception to determine what, if any, relation exists between the perception of small brightness-differences at fairly high levels of illumination on the one hand and the facts of dark-adaptation on the other.

The test-object used for testing shade-perception is a chart composed of ten rows of eight white letters each, on gray back-grounds ranging from very dark to very light.[1] The various gray backgrounds, each bearing a row of letters, are 4 x 18.3 cm., with a white interval 1.8 cm. between. The row on the darkest gray is marked L 1/10, the next 2/10 and so on, the lightest being L 1. The letters are of the

[1] Plate V. of DeWecker et Masselon, 'Échelle Metrique pour Mesurer l'Acutié Visuelle.' O. Doin et fils, Paris, 1914.

gothic style and approximately 7.6 mm. high, designed to subtend 5 minutes angle at 5 meters and would thus represent 20/20 vision if printed in black and white. The chart was illuminated by a 40-watt vacuum tungsten filament lamp, with reflector, from approximately 80 cm. distance, the room otherwise being in darkness.

Table IV

The Results of the Shade-perception Experiments, Compared with the Dark-adaptation Results: (1) Absolute Threshold and (2) Individual Speed of Recovery.

In the latter the class-numbers are plotted, cf. Table III. The shade-perception chart was used at 5.1 meters except as specified.

Obs.	Vision		Dark Adaptation.		Shade Perception		Remarks
	Uncor.	At Expt.	AT, Mm.	Speed Class	Lt. Adpt.	Dark Adpt.	
R		20/15− 20/15−	94.2 92.0	5/5	1/10−4 1/10−3		
O		20/15 20/15	88.5	5/4	9/10−1	9/10+2	
Sh		20/15 20/20	88.0	4/−	7/10−2	6/10−2	
G	20/20− 20/20−	20/15+ 20/15+	88.0	2/3	5/10−2	6/10−1 7/10−4	
Ho	20/30 20/20−	20/10− 20/10−	87.2	2/−	9/10+4		
Co	20/200− 20/200−	20/15−4 20/15−4	86.0	3/4	5/10−1 6/10−2	6/10−4	
L	20/33 20/25	20/10− 20/10−	82.5	2/1		9/10−1+3	At 4.8 m.
W	20/200 20/200	20/15 20/15	83.5	4/5	7/10−1 8/10−1 9/10−3		
W			82.0		9/10+0		
Du	20/70 20/70	20/15 20/15	81.0	1/3	10/10−3	10/10−7	
Hn		20/30−2 20/30	79.5	3/3	9/10−1		At 3.4 m.
Cr		20/15 20/15	77.0	1/2	9/10+1	9/10−1	

The results are given in Table IV., where following the observers' designations are given (1) visual acuity without correction when glasses are worn; (2) vision as applying to the experiment, corrected in case glasses were worn at the time; (3) the absolute (dark-adapted) threshold (mm. scale); (4) the rating with respect to speed of recovery of the same (AT–15, Table III.); (5) the performance with the DeWecker et Masselon chart, light-adapted; (6) the same, dark-adapted.

Investigations with this chart are unsatisfactory, probably arising from the fact that the letters upon it are, with respect to size, too near the visual acuity threshold. It would have been desirable to have a chart in which the former was put out of consideration by having the letters so large that visual acuity, in the usual ophthalmologic sense, could be ruled out.

The chart was actually used at 5.1 meters distance. In the case of observer L, the distance was slightly less, 4.8 meters, due to a purely fortuitous circumstance. In the case of Hn it was 3.4 meters, owing to the fact that this observer could not read even the first line at a greater distance. No relationship is known by which these readings could be corrected so as to be strictly comparable with the others.

Another difficulty with this chart is the fact that the observer is frequently able to read several lines, excepting, in each line, an approximately equal number of letters. That is to say, there is more divergence in visibility between letters of the same line than between one line and the next (see observers G, Co, W, Table IV.).

The shade-perception readings under the head 'light-adapted' were taken either just before the dark-adaptation experiment, or in some cases at another time. Those in the next column, headed 'dark-adapted' were taken at the close of the dark-adaptation run, immediately upon the turning on of the light. The latter gives in most cases a somewhat poorer indication, usually by a few letters only, occasionally by as much as a line. In one or two cases the reverse is noticed (O, G) sometimes plainly the result of memory of

the chart and of practice (compare Co, W, under 'light-adapted,' with G). The chart was difficult and uncertain to work with, and the effect of dark-adaptation, to which a slight falling off might in some cases be attributed, was very transient and soon wore off or became masked as the observer studied the chart and became familiar with it. In what follows the effect of the state of adaptation upon shade-perception will be ignored, and for each observer his best reading will be used, for comparison with the extent and speed of his dark-adaptation.

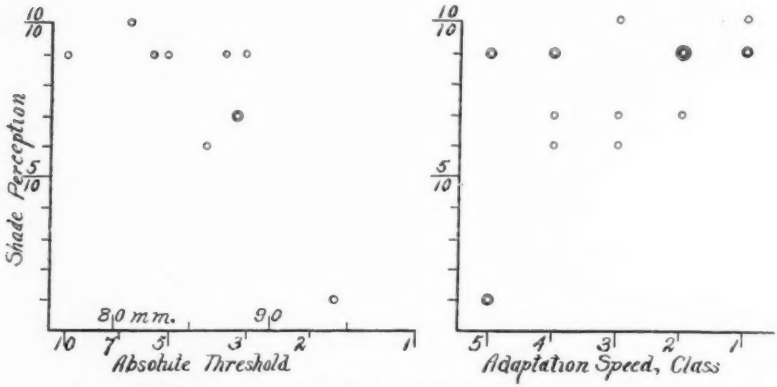

FIG. 7. Relation between dark-adaptation and shade-perception, the latter taken with the DeWecker and Masselon 'light sense' chart. In the figure on the left the abscissæ are absolute threshold, in millimeters of the scale above the line and in millionths of one candle per square meter below. This unit is equal to one hundred of those used in Column 5, Table II.

In Fig. 7 the shade-perception readings are plotted (*a*) against the absolute threshold and (*b*) against the speed-rating (AT–15, Table III.). The numerical designation of the last line that the subject attempted to read was plotted, disregarding the few letters missed, since there was no way of appraising the significance of the latter. In so far as any correlation is shown, the sensitiveness to shade difference relates itself in an inverse sense with the absolute threshold (*a*, Fig. 7) and in a direct sense with the speed of recovery (*b*, Fig. 7). These results are unsatisfactory. A more

appropriate and less ambiguous form of test chart (or other apparatus) for measuring the sensitiveness to small brightness-differences, and further investigation, are necessary for definite conclusions.

Plotting the shade-difference results against visual acuity, measured by means of the Snellen chart, either with or without the usual correction, showed even less correlation than when the former were plotted against the dark-adaptation results as in Fig. 7.

Summary

1. Upon investigation of fifteen subjects it appears that the limit of vision in dark adaptation (absolute threshold), measured by the least brightness at which gross form may be recognized, is variable within extreme limits expressed by the ratio of 7.4 to 1. These limits lie between 1 and 10 millionths of one candle per square meter.

2. The rate of recovery, after dark-adaptation is disturbed by a standard exposure to light, is also variable as between individuals and by no means always in a sense corresponding with the value of the absolute threshold. The extremes of variation between individuals as to time of recovery are as 4.5 to 1 and as 2.5 to 1 for a longer and shorter period of blinding respectively. Recovery, as here used, means the individual's return to a definite multiple (by the factor 4.7) of his own absolute thresold.

3. The time of recovery to the point of distinguishing a test-object of standard brightness is to be looked upon as a function of both of these, the one or the other preponderating in effect according to the test stimulus chosen. For a test stimulus 4.7 times the (geometric) mean absolute threshold of all observers, the extreme variations in time are expressed as 8.7 to 1 and 2.75 to 1 for a longer and a shorter period of blinding respectively.

4. The times of recovery are less diverse after a short blinding (15 seconds, 13 candles per square meter) than after a longer one (5 minutes, same), and in the former case recovery takes place, on the average, in about one third the

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time, or probably less when all antecedent conditions are equalized.

5. The occurrence, in the course of dark-adaptation, of more or less definite arrests in the decrease of the threshold

TABLE V

THE OBSERVERS: AGE, VISION AND REFRACTION

Obs.	Age	Refraction			During Experiment	
		Vision Uncorrected	Correction or Remarks	Vision Corrected	Glasses Worn	Vision
R	46	O.D. 20/15−	+0.75 sph		No	20/15−
		O. S. 20/15−	+1.00 sph			20/15−
Do	37	O.D. 20/30−	+1.00 sph +1.00 cyl. ax. 95°	20/15	Yes	20/15
		O. S. 20/30−	+1.00 sph +1.00 cyl. ax. 85°	20/15		20/15
O	24	O.D. 20/15	Slight marginal blepharitis		No	20/15
		O. S. 20/15				20/15
Sh	45	O.D. 20/15			No	20/15
		O. S. 20/20				20/20
G	36	O.D. 20/20−	−0.25 sph +1.25 cyl. ax. 84°	20/15+	Yes	20/15+
		O. S. 20/20−	−0.75 sph +2.00 cyl. ax. 95°	20/15+		20/15+
Ho	39	O.D. 20/30	+1.37 sph +0.87 cyl. ax. 70°	20/10−	Yes	20/10−
		O. S. 20/20−	+1.37 sph +0.62 cyl. ax. 110°	20/10−		20/10−
Si	27	O.D. 20/20	+0.62 sph +0.12 cyl. ax. 90°		No	20/20
		O. S. 20/20	+0.75 cyl. ax. 90°			20/20
Co	47	O.D. 20/200−	−2.75 sph −0.62 cyl. ax. 5°	20/15−4	Yes	20/15−4
		O. S. 20/200−	−1.75 sph −0.62 cyl. ax. 175°	20/15−4		20/15−4
W	39	O.D. 20/200	−2.50 sph −0.50 cyl. ax. 100°	20/15	Yes	20/15
		O. S. 20/200	−2.75 sph −0.75 cyl. ax. 100°	20/15		20/15
B	41	O.D. 20/20−1	+1.00 sph −0.37 cyl. ax. 100°	20/15*	Yes	20/15*
		O. S. 20/20−3	+1.00 sph −0.37 cyl. ax. 80°	20/15*		20/15*
L	55	O.D. 20/33	−0.75 sph +1.50 cyl. ax. 48°	20/10−	Yes	20/10−
		O. S. 20/25	−0.75 sph +1.62 cyl. ax. 92°	20/10−		20/10−
Du	25	O.D. 20/70	−2.00 sph −0.25 cyl. ax. 120°	20/15	Yes	20/15
		O. S. 20/70	−1.75 sph	20/15		20/15
Hn	49		−0.50 cyl. ax. 180°	20/30−2	Yes	20/30−2
			−0.50 cyl. ax. 180°	20/30		20/30
M	36	O.D. 20/20−1			No	20/20−1
		O. S. 20/20+4				20/20+4
Cr	23	O.D. 20/15	Possible slight snow-blindness from flying over snow fields some months previously.		No	20/15
		O. S. 20/15				20/15

*Glasses worn by B contained correction for slight presbyopia. Vision was thereby somewhat fogged at 20 feet, but presumably equivalent to 20/15 at the distance used, 52 cm.

suggests the independent working of two physiologic mechanisms. These halts occur, more or less definitely, in 18 out of 52 courses of dark-adaptation investigated, and appear as more or less definite 'terraces' on the rising slope of the curve.

6. A definite photometric knowledge of the minimum

light conditions under which the flier may be called upon to use his vision is necessary before a test method can be intelligently proposed, or further investigation advantageously carried on.

7. The relation between the limit and speed of dark-adaptation on the one hand, and sensitivity to shade-difference under relatively high illumination on the other, is not clear. It would appear that shade difference sensitivity is related to absolute (dark-adapted) sensitivity in an inverse sense and to the speed of recovery of dark-adaptation in a doubtful, possibly direct sense; but the results are such as to leave these conclusions in doubt.

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A DIRECT DEDUCTION OF THE CONSTANT PROCESS USED IN THE METHOD OF RIGHT AND WRONG CASES

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The object of this article is to show how the Constant or Fechner-Müller-Urban Process of calculating thresholds can be directly deduced from first principles. The historical development of the process is first traced, and then contrasted with the direct deduction. The latter throws into clearer relief the nature of the assumptions and approximations made, and justifies Urban's, as against Müller's, Table of Weights.

I. Introduction

The Constant Process is employed to fit the integral of a 'normal' curve to data accumulated by the Method of Right and Wrong Cases. The process has been given various names. Often the name 'Method of Right and Wrong Cases' has been used so as to include not only the method of experimenting but also the above process of dealing with the data after collection. But since many other mathematical processes can be applied to the same data it is better to use a second name. Professor G. E. Müller calls it the 'Konstanzmethode.' Professor Urban speaks of the '$\Phi(\gamma)$ Hypothesis'[1] and the 'Konstanzmethode,'[2] and I have elsewhere called it the 'Constant *Process*,'[3] using the word process to indicate a process of calculation, and leaving the word method to mean a method of experimenting. The process can be

[1] F. M. Urban, 'Die psychophysischen Massmethoden als Grundlagen empirischer Messungen,' *Archiv f. d. ges. Psychol.*, **16**, 1909, p. 366.

[2] F. M. Urban, 'Die Praxis der Konstanzmethode,' Leipzig, 1912.

[3] G. H. Thomson, 'A Comparison of Psychophysical Methods,' *Brit. Journ. Psychol.*, **5**, 1912, p. 210.

applied to data collected by other methods, *e.g.*, The Method of Non-Consecutive Groups.[1]

In the descriptions of the Constant Process given by Professor Müller[2] there is an error of omission which remained undetected until the appearance of Professor Urban's article already quoted, in 1909. Historically the Constant Process arose as an application, to a particular problem, of the Method of Least Squares, of which latter I next give a short account.

II. The Method of Least Squares

When observations have given a certain number of observation equations for a smaller number of unknowns, it is impossible in general to find exact solutions for the whole set of equations, for they are, owing to observational errors (and, in psychophysics, also owing to subjective variations) more or less inconsistent with one another. In such a case what is called the Method of Least Squares can be applied to find what are, with certain assumptions, the most probable values of the unknowns. Let there be k equations for g unknowns ($k > g$), and suppose that these equations are linear, as follows:

$$a_1x + b_1y + c_1z + \cdots + f_1u + g_1w + \alpha_1 = 0,$$
$$a_2x + b_2y + c_2z + \cdots + f_2u + g_2w + \alpha_2 = 0,$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$a_kx + b_ky + c_kz + \cdots + f_ka + g_kw + \alpha_k = 0.$$

Moreover, suppose that these equations are not equally trustworthy, but are based upon various numbers of experiments n_1, n_2, $\cdots$, n_k. Then the rules of the Method of Least Squares run as follows:

To find the 'normal equation' for x, multiply each equation (1) by its weight n and (2) by the coefficient of x in that

[1] G. H. Thomson, *loc. cit.*, p. 204.

[2] G. E. Müller, 'Die Gesichtspunkte und die Tatsachen der psychophysischen Methodik,' Wiesbaden, 1904, par. 11: 'Ueber die Massbestimmungen des Ortssinnes der Haut mittelst der Methode der richtigen und falschen Fälle,' *Pflüger's Archiv*, Bd. 19, 1879, pp. 191 ff., and elsewhere.

equation, and then add all the equations together. Similarly, 'normal equations' can be found for $y, z, \cdots, u$ and w. There will thus be exactly as many normal equations as unknowns, and the values of the latter found therefrom are the 'most probable' values, provided we assume that the errors or variations arising in our experiment were all 'normally distributed.'

III. A Description of the Fechner-Müller-Urban Process as it Arose Historically

This process arose from an application of the above rule to a particular problem in psychophysics. Certain stimuli

$$r_1, r_2, r_3, \cdots, r_k$$

were presented each n times,[1] in a certain way, to a subject, who gave at each stimulus value a different proportion of the looked for reaction, these proportions being

$$p_1, p_2, p_3, \cdots, p_k.$$

The assumption is now made that

$$p' - \tfrac{1}{2} - \frac{1}{\sqrt{\pi}} \int_0^{h(r-S)} e^{-x^2} dx = 0, \qquad (1)$$

p' being a function of which the above p's are experimental values, while S is the required 'threshold' and h is its 'precision,' $\sigma = 1/(h\sqrt{2})$ being the 'standard deviation' of the distribution. By inserting in equation (1) the k experimental pairs of values of p and r we obtain k observation equations for the two unknowns S and h. The equations will never in practice be exactly consistent with each other, and no pair of values S and h will exactly satisfy them all, but will leave small residuals $v_1, v_2, v_3, \cdots, v_k$ instead of giving zero in each case.

The Fechner-Müller argument then goes on (erroneously, as Professor Urban showed later) to postulate that the best

[1] To avoid unnecessarily complicating the argument I assume each was presented n times. If the different r's are presented different numbers of times a 'weight' in the ordinary sense of the word has to be attached to each observation equation in what follows, proportional to the number of presentations of that stimulus.

pair of values S and h is that which makes the sum of the squares of these residuals, Σv^2, a minimum. As the rules for forming normal equations are only intended to apply to linear observation equations, however, a plan had to be devised to replace the above equations, which at present include integrals and are anything but linear, by linear equations. This was ingeniously managed by Professor Müller by means of the 'method of weights,' as follows:

In tables of the probability integral we find values of p and corresponding values γ of the upper limit of the integral of equation (1). Fechner's Fundamental Table, as it is called, is merely such a table with rather wide intervals specially published for psychologists at that time. We can therefore write down those k values of γ which correspond exactly with our k experimental values of p, and equate them to the k values obtained by inserting $r_1, r_2, \cdots, r_k$ in the upper limit $h\ (r - S)$. We thus have k equations of the form

$$\gamma = h(r - S), \tag{2}$$

where the r's are the experimental stimulus values, and the γ's are found (with the aid of a table) from the experimental p's, and S and h are required. If we write $hS = c$ these become linear equations in h and c, viz.,

$$\gamma - hr + c = 0. \tag{3}$$

Any pair of values h and c inserted into the k equations (3) will leave residuals $u_1, u_2, u_3, \cdots, u_k$. If we apply the rules of the Method of Least Squares to *these* equations as they stand, the values of h and c obtained from the normal equations will be those which make Σu^2 a minimum. This however is not what we want, we want Σv^2 to be a minimum, the sum of the squares of the residuals of the equations (1). We could obtain this if we were to find a set of 'weights' $\Gamma_1, \Gamma_2, \Gamma_3, \cdots, \Gamma_k$ to use on the equations (3) such that each (Γu^2) will equal the corresponding v^2, for the normal equations of the equations (3) thus weighted will then make $\Sigma(\Gamma u^2)$, that is Σv^2, a minimum. The problem of finding these weights is in effect the problem of finding what change in p

corresponds to a change $\delta\gamma$ in γ. We have

$$p - \tfrac{1}{2} = \frac{1}{\sqrt{\pi}} \int_0^{\gamma} e^{-x^2}\, dx, \tag{4}$$

and therefore

$$\delta p = \frac{1}{\sqrt{\pi}} \int_{\gamma}^{\gamma+\delta\gamma} e^{-x^2}\, dx. \tag{5}$$

When $\delta\gamma$ is sufficiently small this integral, which is the area of a narrow element of a curve, may be replaced by the rectangle found by $\delta\gamma$ (width) and $e^{-\gamma^2}$ (height), *i.e.*,

$$\delta p = \frac{e^{-\gamma^2}}{\sqrt{\pi}}\, \delta\gamma. \tag{6}$$

$\delta\gamma$ corresponds to a residual u, and δp corresponds to a residual v, so that, since Γu^2 has to equal v^2, the sought for weights Γ are given by

$$\Gamma = \frac{e^{-2\gamma^2}}{\pi}. \tag{7}$$

It is convenient that the weights should run from 0 to 1, and the π is therefore omitted in the tabulated values. As weights are merely relative quantities this has no effect on the final result of the calculations. These Müller weights are to be found in several textbooks of experimental psychology. *They are however incorrect, or rather incomplete, and should be entirely dropped for Urban's Weights.*

Urban's weights differ from Müller's in that they contain further the factor $1/[4p(1 - p)]$. The need for this factor was overlooked by Professor Müller and was first pointed out by Professor Urban (*op. cit.*, 1909). It does not arise from the transition from the equations (1) to the equations (3), but exists previously to this, because the standard deviation of experimental determinations of a constant proportion p is equal to $\sqrt{np(1 - p)}$, where n is the number of trials in each experiment, the distribution being binomial in form. If we write

$$P = \frac{e^{-2\gamma^2}}{4p(1 - p)}, \tag{8}$$

the P's are Urban's weights which should replace Müller's

weights. The correctness of Urban's weights is particularly clearly demonstrated in the direct proof of the Constant Process given later in this article.

We have therefore k equations, linear in h and c, each with weight P, as follows:

$$\begin{aligned} &\gamma_1 - hr_1 + c = 0, \text{ weight } P_1, \\ &\gamma_2 - hr_2 + c = 0, \text{ weight } P_2, \\ &\cdots\cdots\cdots\cdots \\ &\cdots\cdots\cdots\cdots \\ &\gamma_k - hr_k + c = 0, \text{ weight } P_k. \end{aligned} \tag{9}$$

By the ordinary rule of the Method of Least Squares the normal equations for c and h are therefore

$$\begin{aligned} [P\gamma] - [Pr]h + [P]c &= 0, \\ [P\gamma r] - [Pr^2]h + [Pr]c &= 0, \end{aligned} \tag{10}$$

where the square brackets are the sign used by Gauss to indicate summation from 1 to k, traditionally retained in normal equations. From those h and c, and therefore S, can be calculated.

With this historical development of the Constant Process may now be compared the following direct deduction, where the assumptions and approximations are particularly clearly marked, the rules of the Method of Least Squares are avoided, and Urban's weights are seen to arise from first principles.

IV. Direct Deduction of the Constant Process

Let there be k different stimuli

$$r_1, r_2, r_3, \cdots, r_k,$$

at each of which a subject is repeatedly tested to ascertain whether or not he reacts in a certain way.

First Assumption.—Assume that for each stimulus r there exists a constant probability p' that the reaction in question will occur, so that we have the set of theoretical probabilities

$$p_1', p_2', p_3', \cdots, p_k'.$$

Throughout our argument we shall use dashed letters for theoretical values, undashed letters for observed values.

Now let n experiments be made with each stimulus, and let the proportions of reactions at the respective stimuli be

$$p_1, p_2, p_3, \cdots, p_k.$$

What is the probability W of obtaining this particular set of experimental values for the probabilities? The probability of obtaining any p as an experimental value of the corresponding p' is, from first principles, equal to

$$\omega = \frac{n!}{(pn)!\ (qn)!}\, p'^{pn} q'^{qn}, \tag{11}$$

where

$$q = 1 - p,$$
$$q' = 1 - p',$$
$$n! = n(n-1)\ (n-2) \cdots 3, 2, 1$$

and since the n experiments made to find one p are quite independent of the n experiments made to find any other p, the probability of the simultaneous occurrence of $p_1, p_2, p_3, \cdots, p_k$ is the product

$$W = \omega_1\, \omega_2\, \omega_3 \cdots \omega_k. \tag{11a}$$

Now each p' must, quite generally, be a function of the stimulus r and of a number of parameters $\alpha, \beta, \gamma, \cdots$. Those values of $\alpha, \beta, \gamma, \cdots$, will be the most probable *which make W a maximum*, and a necessary condition for this is that

$$\frac{dW}{d\alpha} = \frac{dW}{d\beta} = \frac{dW}{d\gamma} = \cdots = 0. \tag{12}$$

These equations are those required to find $\alpha, \beta, \gamma, \cdots$, when the form of the function p' has been decided upon. When the value of W is inserted from (11*a*) each equation of the system (12) assumes the form

$$\sum_1^k \frac{1}{\omega}\frac{d\omega}{d\alpha} = 0$$

and on further substituting the values of ω from (11) the sys-

tem (12) becomes

$$\sum_1^k \frac{p - p'}{p'q'} \frac{dp'}{d\alpha} = \sum_1^k \frac{p - p'}{p'q'} \frac{dp'}{d\beta} = \cdots = 0. \qquad (13)$$

It is at this point, therefore, that the distinguishing factor of Urban's weights, viz., $1/p'q'$, makes its appearance. It arises from equation (11) and the assumption which precedes that equation. We have not yet made any assumption as to the relation between p' and r.

Second Assumption.—Assume now that p' is given by

$$p' - \tfrac{1}{2} - \frac{1}{\sqrt{\pi}} \int_0^{h(r-S)} e^{-x^2} dx = 0. \qquad (14)$$

Thus the parameters are two in number, S and h, and we have on differentiating

$$\frac{dp'}{dS} = \frac{-h}{\sqrt{\pi}} e^{-h^2(r-S)^2} = \frac{-h}{\sqrt{\pi}} e^{-\gamma'^2},$$

$$\frac{dp'}{dh} = \frac{r - S}{\sqrt{\pi}} e^{-h^2(r-S)^2} = \frac{r - S}{\sqrt{\pi}} e^{-\gamma'^2},$$

where we have written

$$\gamma' = h(r - S) \qquad (14a)$$

for abbreviation. From eqn. (13) we therefore have, by substituting for dp/dS and dp'/dh,

$$\sum_1^k \frac{p - p'}{p'q'} h e^{-\gamma'^2} = 0, \qquad (15)$$

$$\sum_1^k \frac{p - p'}{p'q'} (r - S) e^{-\gamma'^2} = 0. \qquad (16)$$

In (15) the h can be brought outside the Σ and then dropped: while (16) can be written

$$\sum_1^k \frac{p - p'}{p'q'} r e^{-\gamma'^2} - S \sum_1^k \frac{p - p'}{p'q'} e^{-\gamma'^2} = 0,$$

of which the second term is zero by (15). We therefore have as simplified forms of (15) and (16) the equations

$$\sum_1^k \frac{p - p'}{p'q'} e^{-\gamma'^2} = 0, \qquad (15a)$$

$$\sum_1^k \frac{p - p'}{p'q'} r e^{-\gamma'^2} = 0. \qquad (16a)$$

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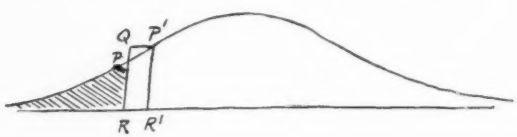
Herein the p's and r's are known, and the p''s, q''s, γ''s are functions of S and h given by (14) and (14a), ($q' = 1 - p'$). These two eqns. (15*a*) and (16*a*) are the strict eqns. for finding S and h, and *up to this point there are no approximations*. A final test of any Gaussian values of S and h, in whatever manner found, must be that they give values of p', q' and γ' which satisfy (15*a*) and (16*a*).

Except by trial or graphical methods however these equations are not soluble, and approximations are necessary to enable them to be handled. These approximations we now proceed to discuss.

Consider the quantity $p - p'$, the difference between the experimental and theoretical values of the probability at the stimulus r. From p we can find in tables of the probability integral the value of γ, the upper limit of the integral, which corresponds to p. This γ is then an experimental value of the γ' of eqn. (14*a*). From γ we can in imagination find, if we suppose the S and h known for the moment, a value r' from

$$\gamma = h(r' - S), \tag{17}$$

r' will in general differ from the real value r. If we draw a normal curve as in the accompanying diagram, and if R is the position of the stimulus r, then the theoretical value p' is the area of the curve up to the ordinate at R. Let the real value p be (say) greater than this, then p can be repre-



sented as the area to a point a little further on, R', corresponding to the value r'. The quantity $p - p'$ is then represented by the area $R\ PP'\ R'$. If this is narrow it may be replaced without great error by the rectangle $R\ Q\ P'R'$, *i.e.*, we write as our *first approximation*

$$p - p' = (r' - r)e^{-\gamma^2}, \tag{18}$$

$e^{-\gamma^2}$ being the ordinate $R'P'$. In doing this we have made our *third assumption*, viz., that the experimental values p can be sufficiently well fitted to make each $p - p'$ small enough to replace by a rectangle. *This will for example not be the case if there are gross irregularities, such as 'reversals of the first order,' in the sequence of p's.* The Constant Process should therefore not be applied to such data; if it is, the values obtained from the approximate normal equations (10) will not satisfy the exact equations (15*a*) and (16*a*) with sufficient accuracy.

On inserting the value of $p - p'$ from eqn. (18) in the eqns. (15*a*) and 16*a*) we obtain

$$\sum_1^k \frac{r - r'}{p'q'} e^{-2\gamma^2} = 0, \tag{15b}$$

$$\sum_1^k \frac{r - r'}{p'q'} re^{-2\gamma^2} = 0. \tag{16b}$$

Second Approximation.—To further simplify these, we next replace all the theoretical values except r' by their observed values, *i.e.*, we write

$$\sum_1^k \frac{r - r'}{pq} e^{-2\gamma^2} = 0, \tag{15c}$$

$$\sum_1^k \frac{r - r'}{pq} re^{-2\gamma^2} = 0. \tag{16c}$$

This approximation also rests on the third assumption above. The equations are now the same as the normal equations (10) as can be seen as follows.

Write as before

$$P = \frac{e^{-2\gamma^2}}{4pq} \tag{8}$$

and use

$$\gamma = h(r' - S) \tag{17}$$

to eliminate r'. We thus obtain

$$\sum_1^k P \frac{hr - \gamma - Sh}{h} = 0, \tag{15d}$$

$$\sum_1^k Pr \frac{hr - \gamma - Sh}{h} = 0. \tag{16d}$$

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Bring the $1/h$ outside the summation, drop it, and use the Gauss notation $[x]$ for $\sum_1^k x$, and we obtain

$$\begin{aligned} [Pr\,]\,h - [P\gamma] - [P]\,Sh &= 0, \\ [Pr^2]\,h - [Pr\gamma] - [Pr]\,Sh &= 0, \end{aligned} \tag{10}$$

which are identical with our former equations (10), since $Sh = c$.

TIME RELATIONSHIPS IN THE FORMATION OF ASSOCIATIONS

BY H. A. CARR AND A. S. FREEMAN

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This paper presents experimental data from the field of animal psychology concerning two related problems. (1) The first question concerns the relative merit of simultaneous and successive presentation in relation to the speed of learning. The animals were required to associate two factors which we may term *A* and *B*. With one group the two terms were presented simultaneously and in the other they were presented successively with an interval of approximately 1 second between them. The comparative number of trials necessary to establish a given strength of functional connection constitutes the measure of the relative efficacy of the two methods of presentation. (2) The second problem concerns the readiness with which a given temporal association will function in a backward as compared to the forward direction. One group of rats learn the association in the order *A*—*B*, while in a second group the terms are presented in the order *B*—*A*. In the test experiment the terms are required to function in the order *A*—*B* for both groups. Comparative records were taken of the number of trials necessary to attain a functional connection of a given strength.

A diagram of the apparatus is given in Figure 1. The dimensions of the box are 24 x 36 inches. The runways are 4 x 6 inches. From the food box emerges the entrance alley which divides into two paths (*R* and *L*) both of which return to the food box. The three openings into the food box can be closed as desired by means of sliding doors (1, 2 and 3). The return paths were broken up by projections from alternate sides of the alley. This device prevented the animals from sensing from a distance whether the door leading to the food was open or closed. Two electric buzzers (*A*) were

located in each return alley. With the exception of the food box and the ends of the return paths the apparatus was covered with a glass top.

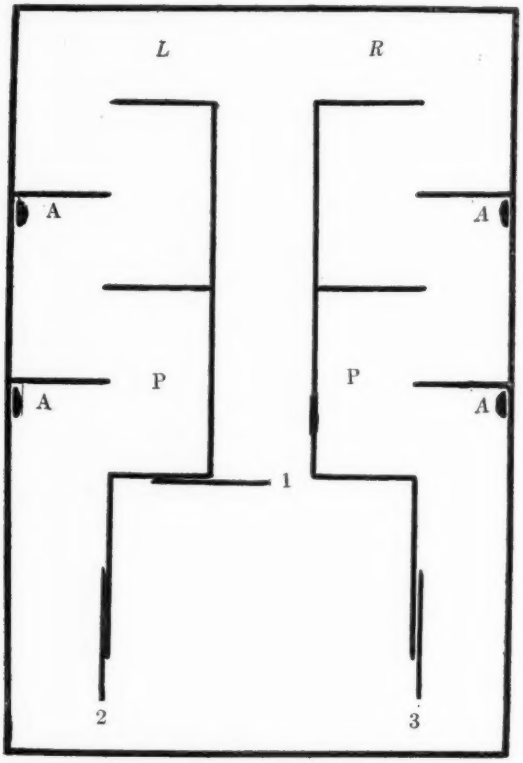

FIGURE 1. Diagram of Apparatus.

All animals were given preliminary, training and test series of trials. In the preliminary series one of the return paths was invariably blocked for each trial. The right and left paths were opened alternately. The rat was inserted into the entrance alley from the food box and allowed to choose between the return paths at random. Naturally the open path will be chosen in approximately 50 per cent. of the trials. The number of consecutive runs per day was

gradually increased from four to a maximum of twenty. The solution of this phase of the problem involved the choice of one of the return paths, the habit of traversing it to the end, entrance into the food box if the path is open, and if the path is blocked a return and choice of the opposite path. The objects of this series were to train the animals to run twenty consecutive trials per day, to eliminate loitering, hesitations, indecisions, and unnecessary activities, and to teach the animal the trick of turning around immediately in response to a closed door and selecting the opposite pathway to the food.

The object of the training series was to establish an effective association between an auditory stimulus (*A*) produced by the electric buzzers and the act (*B*) of turning around and retracing the path when a closed door was encountered. This response had already been thoroughly inculcated by the preliminary series of trials. The procedure for all animals involved the following steps: Both return doors were closed. The rat was introduced into the entrance alley from the food box. The rat traversed the entrance alley and entered one of the return paths. In 20 per cent. of the trials the door of the pathway chosen was opened after it was entered; in the remaining trials the door of the path not chosen was opened. In the first case the rats secured food by means of the selected path; in the second case the rats invariably found the selected pathway to be blocked and that food could be secured only by means of the opposite path. When the door of the selected path was opened, no auditory stimulus was given; when the pathway way was blocked, the auditory stimulus was invariably given in a certain temporal relation to the act of turning around in response to the closed door. In all cases the duration of the stimulus approximated an average of .8 seconds. From this point the procedure differed according to the group. With group 1 consisting of eight rats the stimulus was given while the animal was turning around. The two factors to be associated were thus presented simultaneously. With group 2 consisting of eight animals the buzzers were sounded just

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as the rats passed the point *P* (indicated in the diagram, Figure 1) before they reached the closed door. The average time involved in traversing from point *P* to the closed door approximated 1 second. Consequently the two factors were presented in the order *A*—*B* with a second's interval between them. The third group contained nine rats and with these the stimulus was given at the point *P* after the closed door had been encountered and while the rats were retracing the path. The two factors were presented in the temporal order of *B*—*A* with an interval of approximately one second.

A test series was necessary to determine the degree to which an effective association had been formed. The procedure was the same as that employed in the training series with the exception of the time when the stimulus was given. The stimulus was presented for all groups at some point in the pathway before the rat encountered the closed door. In order to avoid the formation of a position habit, this point was varied in an irregular manner. As in the training series, the door of the selected path was opened and no stimulus given in 20 per cent. of the trials. This procedure prevented the formation of a habit of invariably turning around in the first path chosen. The formation of an effective association between the two factors will be evidenced by an immediate turn whenever the auditory stimulus is given before the closed door is encountered. Since we desired to measure the gradual growth of the association, it was necessary to interpolate the test trials at regular intervals during the training series. Moreover the number and frequency of the interpolated trials must increase as the problem is mastered. It is unnecessary to give this schema of progression. Suffice it to say that the increase relative to the degree of mastery was the same for all animals.

In groups 1 and 3, progress was measured by the increasing percentages of correct responses made during the test series. A correct response consists of an immediate turn when the auditory stimulus was presented, and traversing the whole length of the path in the 20 per cent. of the trials in which no stimulus was given. Since the latter response

had become inculcated during the preliminary series, mistakes in these trials were rare. As a consequence the percentage records of these groups will begin at 20 and increase to 100 as the response to the auditory stimulus is acquired. With group 2 as the problem is mastered there is nothing to prevent the animals from responding to the stimulus during the training series. The purpose of a test series with this group is mainly to prevent the formation of a position habit. Consequently the progress of this group was measured by the increasing percentages of correct responses in both the training and test series. Since no stimulus was given in 20 per cent. of the trials and these responses were invariably correct, the initial records approximate 20 per cent. and the values will increase to 100 per cent. as the association between auditory stimulus and the act of turning is mastered.

The learning records of the three groups are represented by the graphs of Figure 2. Graph 1 represents the values for the group for which the two factors were presented simultaneously. The records for the group in which the stimulus was given after the act of turning are plotted in graph 3. With both groups the values represent the percentage of correct responses made in the test trials given during each consecutive 100 of total trials. Graph 2 gives the records of the group in which the stimulus was presented before the act with which it was to be associated, and these values are the percentages of correct responses made during each consecutive 100 of training and test trials. These percentage values are plotted in relation to the total number of training and test trials. This procedure is justified on the ground that the test trials probably offered as much opportunity for learning as did the training series. Limitation of time and an accident to a number of the animals prevented a continuance of the experiment beyond a total of 1,400 trials for each animal.

The following conclusions are justified by an inspection of the data:

All curves start at approximately the 20 per cent. level. This result is due to the fact that in 20 per cent. of the trials

the door of the path selected was opened and no stimulus was given. The habit of exploring a pathway to its end was inculcated by the preliminary series of trials, and this mode of response was continued during the training and test trials. Such responses were counted as correct. Progress in associating the sound with the act of turning is thus indicated by a rise of the curve above the 20 per cent. level.

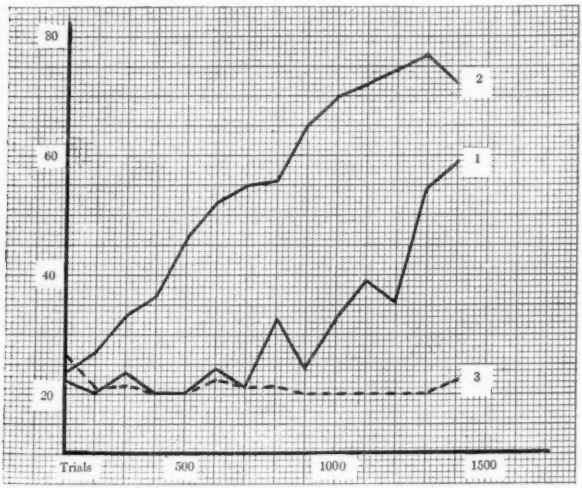

FIGURE 2. The graphs represent the percentages of correct responses per 100 trials. Graph 1 gives the group record for simultaneous presentation; Graph 2 represents the values for successive presentation; Graph 3 records the progress of the group for which the association was tested in the reverse order from that in which the terms were presented.

With our conditions successive presentation of the two terms constitutes a much more favorable method for their association than does simultaneous presentation. This fact is apparent from a comparison of graphs 1 and 2. With successive presentation four of the eight rats attained a proficiency of over 90 per cent. of correct responses, while 80 per cent. was the best record attained by any animal given simultaneous presentations. It is of course possible

that the final records of the two groups would have been approximately identical if the experimentation had been continued until complete mastery of the problem had been effected.

An effective association can be readily formed over an interval of one second provided this interval is filled with some given definite activity.

Associated terms function much more readily in a forward than in a backward direction. Within the time limits of our experiment there is no indication that the third group was making any progress in establishing an association that would function in a backward direction. This general statement holds for each individual as well as for the group as a whole. It is possible that some progress would have been manifested if the experiment had been continued. Such progress might be due, however, to the training effect of the test trials alone.

The curve of learning for simultaneous presentation is one of positive acceleration. That for successive presentation approximates a straight line ascent with some indication of a slight negative acceleration. This difference indicates that the type of curve is a function of the temporal mode of presentation. The result is interesting in comparison with Wylie's results.[1] Our apparatus and procedure were the same as those of Wylie in establishing a negative response to an auditory stimulus with the exception of the mode of presentation of the two terms. Wylie gave the auditory stimulus irregularly but more or less continuously while the animal was traversing and retracing the blocked pathway. He invariably obtained a positive acceleration curve in this type of problem. His animals mastered the problem much more readily than did ours, and this fact is probably due to his method of giving the stimulus. A continuous but irregularly broken sound is likely to be more effective than one of such short duration as that employed in our experiment.

So far as we are aware there are no data in the field of

[1] Wylie, H. H., 'An Experimental Study of Transfer of Response in the White Rat,' *Beh. Monog.*, Vol. 3, No. 5.

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animal behavior bearing upon our first problem of the relative merits of simultaneous and successive presentation. The problem has been investigated with human subjects by Bigham,[1] Chamberlain,[2] Wohlgemuth,[3] and Froeberg.[4] In general the data indicate the superiority of the simultaneous mode of presentation. Especially was this result attained in the better controlled experiments. Our data support the superiority of successive presentation. In the human experiments memorizing activities were employed exclusively. Evidently the relative value of the two methods is a function of the kind of subject or the type of activity employed.

Watson's experiment contributes the only data in the comparative field bearing upon our second problem. He tested the ability of rats to run a maze backward after learning it in the forward direction. Considerable ability was manifested. The experiment is not conclusive owing to the fact that animals do considerable retracing while mastering the problem. The subject has been investigated in the human field with memory material by Ebbinghaus, Müller and Pilzecker, and Wohlgemuth. Ebbinghaus employed the relearning method and found a rather strong tendency in the backward direction, but its strength was never equal to that of the forward tendency. With the method of recall, Müller and Pilzecker demonstrated the existence of a backward tendency whose strength was less than that of the forward direction. Wohlgemuth[5] experimented rather extensively varying both method and material. In five cases the forward direction was the stronger, and in two cases the tendencies were approximately equal in strength. He concludes that the forward direction is the stronger when articulation is used in memorizing, but that the two tendencies

[1] Bigham, John, 'Memory,' PSYCHOL. REV., 1894, 1, p. 435.

[2] Chamberlain, A. H., 'A Memory Test with School Children,' PSYCHOL. REV. 1915, 22, p. 71.

[3] Wohlgemuth, A., 'Simultaneous and Successive Association,' *Brit. J. Psychol.*, 1914, 7, p. 434.

[4] Froeberg, Sven, 'Simultaneous versus Successive Association,' PSYCHOL. REV., 1918, 25, p. 156.

[5] Wohlgemuth, A., 'On Memory and the Direction of Associations,' *Brit. J. Psychol.*, 1912, 5, p. 447.

do not differ in strength when articulation is prevented. Our experiment proves that the formation of an association between a stimulus and a motor response by animals is exceedingly difficult and perhaps impossible when the stimulus is presented after the act has occurred.

RETROACTIVE HYPERMNESIA AND OTHER EMOTIONAL EFFECTS ON MEMORY

BY G. M. STRATTON

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A student of mine not very long ago questioned me regarding a puzzling aspect of his recollection of the earthquake of 1906 in San Francisco. And from this I was led to gather reports, partly oral and partly written, from over two hundred students concerning their memory of this and other unexpected crises. Some of the features which appear seem to me to warrant a written account, placing what is perhaps novel into connection with the better-known effects of excitement on our power of recollection.

The effects of excitement due primarily either to bodily or to mental causes may be divided into two kinds, those which are transitory, experienced only during the excitement, and those which are relatively permanent, still noticeable long after the excitement has subsided. Belonging to the first class, there is upon occasion an apparently *general hypermnesia.* One who at the time was in a condition of hypomania told me his surprise at the marked freshening of all his memories; it seemed to him that he could clearly recall the substance of every book he had ever read, and I know him to have been a very wide reader. Beers observed something similar in himself as he passed from depression to elation.[1] Hypermnesia has been observed at the moment of danger from a railway train as well as during asphyxiation: the past as a whole, or some great stretch of it, lies clear before the mind;[2] there has been a wide awakening of dormant memories.

In at least superficial contrast, while yet belonging to the same class of effects, there is a more *selective hypermnesia,*

[1] 'A Mind that Found Itself,' p. 80.

[2] Féré, 'The Pathology of Emotions,' Eng. tr., pp. 156, 295.

where certain rather narrow lines of association are followed: a person during the excitement leaps in memory to particular past events connected with the present by similarity or other motive for selective recall. When one of my students was in the excitement which followed the killing of his first buck, there arose in his mind with unusual vividness the detailed scenes, "as good as forgotten," of an earlier experience in that same country. Or, with another, the sudden news of a friend's death enlivened to an uncommon degree, for a few moments, the recollection of particular and hitherto disregarded experiences years before.

"I have found," writes still another, "that if an event later turns out to be very important I can remember exact details, concerning this event, that I was not aware, at the time, of even perceiving."

And as a further illustration: "About a year and a half ago I met casually at the dedication of a service flag in Oakland a man. We spoke of various trivial things and I did not once think of him as one whom I should ever see again. He was almost forgotten by me and indeed when I met him six months later a re-introduction was necessary. This time, however, we became very good friends, and with the development of our friendship there came back to me suddenly one day the picture of this meeting, the people present, the ceremony, the trivial conversation in all its detail, almost with all the little by-play of motion, etc."

The effect belonging to the second class, the effect still present long after the excitement is past, is more varied—at least the observation of the effect is, perhaps merely because the opportunity for observation is more favorable. First there is *hypermnesia for events experienced during the excitement.* The person recalls in almost photographic detail the total situation at the moment of shock, the expression of face, the words uttered, the position, garments, pattern of carpet, recalls them years after as though they were the experience of yesterday. The following will serve as examples.

In 1906 the father of one of my students was almost fatally injured in a boiler explosion; the moment described is that of receiving word of the accident. "I was standing in the hall a few

steps behind mother. She had opened the door and an intimate friend of my father's was standing there. His blanched face told that he had bad news to tell. Mother read the expression immediately and started forward with these words, 'Oh Mr. ——, something has happened!' The expression on her face was ghastly and this part is all very vivid to me. I recall the words but do not hear the voices. This friend straightened up and said, 'Now don't let me frighten you too much, but there has been an accident (here mother put her hand to her head) at the plant this afternoon.' Mother cried, 'Oh Will! Will!' and started out the door. 'Is he dead?' The beginning of his reply was 'No, no—' but I don't remember the rest. Up until the time I heard the word 'dead' I had stood motionless but now I ran to my mother and put my arms around her, screaming these very inane words, 'What shall I do? What shall I do?' Mr.—— then took me very firmly by the arm and pushed me back, saying in a calm voice, 'What you can do is to be very quiet for your mother's sake and don't cry.' I was somewhat stunned and stood there with my eyes fixed on the hall rug. They were saying something about bringing him home in a few minutes. They had gone into the next room and I heard mother say, 'I'm afraid you're not telling me all. How can they bring him from the hospital if he is so badly hurt?' All this time I was looking at the rug which I can still see plainly. The background was a soft brown and it had a blue and white design over it. Three large diamond-shaped figures were most prominent. They were white and marked off into smaller diamonds by blue lines. For some reason my fancy made them into immense cut glass dishes and I always think of that rug in those terms. There was a blue band which went around the rug and outlined each of the figures. I do not remember leaving the hall, nor do I remember anything more *about mother* until the shock of the earthquake came early the next morning."

The following is from a student's recollection of an automobile accident in 1913. I have directly questioned the writer and am confident that the account has not been 'touched up' for effect. When the collision seemed inevitable, "I gripped the side of the motor to brace myself for the shock and sat there just frozen with terror. I wondered too if I would get blood on my new coat and if my bones would make a noise if they broke. This sounds ridiculous, I know, but I am telling you frankly just what I remember, and what I have been rather ashamed to admit even to myself; it sounds so cold-blooded.

"The man was intoxicated who was driving the other car, and when we turned out on this other road [a detailed diagram illustrates the various positions], instead of going around us, he deliberately left 40 feet of clear road and ran us into the ditch after having struck us broadside. I remember hearing the crash and seeing his front fender strike our mud-guard. I was seated right where it struck, but something saved my feet from being cut off. I felt myself hurled through the air and a hot little knife-stab pain running through the back of my head and neck as I landed right on the back of my head. Then all was oblivion."

But this is by no means the only way in which such shock may work upon our power of recall; there may instead be an unusual reduction of distinctness and fullness of recollection or there may even be a total oblivion of all the immediate circumstances under which the mortal blow fell. *Hypomnesia* may be illustrated by the following taken from my reports.

Some children, one of whom writes the account for me (about four years later), are driving home from school, suddenly to discover that their house is afire. Other and less important events before and disconnected with the fire, and later events, are recalled in vivid and trivial detail, but "after the first discovery I remember in a sort of dazed way things that happened during the hour that I spent comforting the children and helping my mother to save a few things."

Less than a year ago there came to another of my students an intense surprise. Details of the experience preceding and following have been given me, and these arise in memory spontaneously and with remarkable vividness, but the recollections of what occurred *during the exciting events* "can be pictured," says my reporter, "when I call them up, but they do not come of themselves."

Total *amnesia* of the concurrent events, in the cases before me, occurs only where there has been a physical and stunning blow; mental shock alone, in the persons reporting to me, does not have the effect noticed in pathological cases.

These effects, whether of reduction or of heightening, are of course not confined to the instant of perhaps maximal disturbance but may continue for the entire period of the excitement.

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Thus far the effects remaining long after the emotion have been effects upon *concomitant* experiences; the emotion has caught up the current perceptions and the inner observations and has either preserved them vividly and readily accessible or has suppressed them, dissociating them in part or in whole.

But there are also lasting effects upon experiences *that have gone before*, effects that are of opposite quality.

And first there is the well-known *retroactive amnesia*, where the person has no recollection of events preceding the crisis.[1] The shock may make it impossible to recall any experiences during a preceding stretch of days, of weeks, or even of the entire past. Among my data, I find what are perhaps examples, but not clearly so, of this effect, in as much as, in many of those who experienced the earthquake in San Francisco, nothing is remembered of the hours or days immediately preceding the event.

But more interesting, perhaps only because it seems to have received far less attention, is the very opposite effect, namely a *retroactive hypermnesia*, of which I find many instances.

The following tells of scenes during boating which began about half an hour before an exciting occurrence; much of the original narrative is omitted. "My first vivid memory comes when we had reached the boat and were just starting from the shore. There was a small wooden platform about five boards wide from which we stepped into the boat. There were noticeable cracks between the boards of the platform and the wood was wet and frayed along the edges of the cracks. Throughout the boat-ride I do not remember what the other persons in the boat said or did or how they looked. The water was absolutely smooth when we started, but there were no reflections in it because it was already dusk and the high banks of the stream made it seem even darker. Perhaps that is why I remember no colors. On the other side of the stream the bank was flat and was covered with tall rushes. The rushes extended out into the water so the edge of the bank could not be distinctly seen. A short distance farther on there was a bend in the stream. On the inside of the turn there was a limb of a broken

[1] Cf. Féré, 'Pathology of Emotions,' Eng. tr., p. 295; Janet, 'Major Symptoms of Hysteria,' pp. 37 ff.

tree projecting out into the water. It had some rather stubby looking twigs sticking up from it and was itself in the midst of some driftwood and leaves which had accumulated there. At one place we passed under a log bridge and I remember noticing that the bark had been pulled off in places and that what remained was wormeaten. On our way back down the stream we passed close to a bank of large brake ferns and I can distinctly see how each one, as I looked up the bank, seemingly overlapped the one above it, and they seemed to grow smaller and their outlines less clear in a definite degree as they neared the top. I do not remember anything about the end of the ride, or my going up to our cottage except that I know it took place."

The following is from the recollection of the events before an automobile accident. "The 22d [of August] dawned clear in the San Joaquin valley. I arose early and remember wearing a pink gingham dress which was difficult to fasten and of having called upon my cousin to fasten it for me. I remember being rather tired that day and being vexed when asked to run a few errands for my grandmother. We were sitting at the luncheon table when she asked me to go on these errands and her eyes never seemed to me to be so vividly blue as then. There was a canary in the window, too, and I remember his having sung until it was necessary for us to remove his cage. My afternoon was spent in a siesta since it was one of those hot, sultry days of August. About seven o'clock in the evening my aunt, uncle, their two-year-old baby, my two young lady cousins and myself went to Stockton to the theater. It was a motion picture and we started home at half-past nine because the baby was fretting. My aunt, uncle and the baby were seated in the front of the motor while my two cousins and I were in the back. I was quiet and rather serious during the first two miles and did not feel very well. There is a crossroad about three miles from Stockton where we turned off to go to our home. I shall draw a diagram to show the exact position of the cars, and where the accident occurred."

Over two years ago, in the middle of a Sunday afternoon, unexpected word came by telephone of the death of the person's father, a sudden death by accident. "What happened after that call I do not remember nearly so distinctly as the things which had happened during that Sunday before the message came. I remember distinctly running for the car in the morning when going to church, the sermon, people I had never seen before that day who

were in church. I remember the ride home in a machine. The thing which stands out clearest is the discussion a girl and I had when drying the dishes, although in no way was this subject under discussion connected with the events which followed."

The particulars of this last account have been written out for me—the description of the strangers met, the character of the voice of one of them, the outline of the sermon, the name of one of the hymns sung, subject of the substance of the discussion while busied with the dishes. It will be unnecessary to quote these details.

Finally, there is a curious combination of both these latter effects; for the same person the stretch of time preceding the critical event may show an irregular alternation of heights and depressions, vivid recollections followed by a period of utter blank.

"In the spring of 1912 I was living in Beirut, Syria. The Turko-Italian war was in progress. One Saturday morning two Italian battleships appeared in the bay in an engagement with two small Turkish gunboats, which they finally sank. All the events of the early morning are exceptionally distinct, even to slight details. The engagement took place some hours later, and its details are also vivid.

"The time limits which I shall designate below are only approximately correct. My recollection of the first fifteen minutes before the crisis [which came "shortly after nine o'clock" and "lasted about half an hour"] is not very vivid. I know that I was studying—writing a composition. I have a general image of the room in which I sat, and of a few of its details. The half hour previous to that is blank. The hour before that is very clear in my mind. I remember little conversation, but I have distinct memories of all that occurred. The rest of the events of the early morning I can remember, but not picture to myself. I cannot recall what happened the preceding day. The crisis I shall consider as the period from the time the first shell was fired until the firing ceased. The first five to ten minutes are confused. I have a few vivid but disconnected images. The remainder of the period covered by the crisis is very vivid and full of detail. My recollections are both visual and auditory.

"I cannot distinguish the ten minutes following the crisis from the crisis itself in regard to vividness or fullness of detail.

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The succeeding hour marks a gradual decline in the vividness of recollections. Always a diminution in the clarity of my visual images is accompanied by a smaller and smaller amount of detail in the pictures. The next hour is relatively vague. I remember, but cannot picture events. During the next hour and a half my recollections again become very distinct; then gradually fade out. The succeeding three hours are almost blank. Then for 15–20 minutes I again have vivid images. The remainder of that day and the next morning until 7:45 are blank. For an hour and a half thereafter I again have recollections as vivid and as detailed as those of the crisis. The morning of the succeeding day I can recall rather vividly, but with very little detail. Then my memory becomes normal. Throughout, my recollections consist of a series of disconnected pictures with varying amounts of detail."

In another case, preceding the sudden word of an explosion at a mountain mill, there is a period of about an hour of photographically literal recollection; and after that hour and before the fatal news, there is about half an hour during which nothing whatever is recalled.

This from the recollection of events before an earthquake when the student writing was about six years old: "The evening before the earthquake I remember very well. We had all spent the evening with some friends; and as they lived very near our house, we walked home instead of riding. I remember a great deal of the conversation; many remarks were passed as to the weather, and that it was 'real earthquake weather.' I well remember who were at the party and the way in which we passed the evening, also in what the refreshments consisted.

"I only remember that which happened the evening before, not the next morning at all. (I believe the earthquake was about one o'clock in the afternoon.)"

II

Of the permanent *retroactive hypermnesia* in the cases which have come to my notice some further word will perhaps not be amiss. In selecting the material it is obvious that one must keep to cases where the crisis comes wholly without warning. Otherwise there would almost of necessity have been an anticipatory emotion concurrent with the events preceding the crisis and well capable of vivifying them, and there would be no occasion to ascribe their vivid recall to

some back-stroke of the emotion coming only at the time of the crisis.

1. Temporal Features of the Retroaction

The effect in the cases before me rarely goes beyond the day preceding the critical event. More frequently, and in particular when the crisis came early the next morning, it touches merely the latter part of the preceding day. Still more frequently, when the crisis occurred late in the day, the effect is found only in that day. Furthermore, it is noteworthy that occasionally but not always the effect seems to have sharp borders: it does not come on gradually, but suddenly; there is a clear demarcation between the beginning of the vivified and the end of the unaffected territory; and likewise of the close of the hypermnesic period. Not infrequently, as has already been stated, the antecedent hypermnesia is followed, even before the critical event, by hypomnesia or amnesia. But in this respect, as in so many others, there are decided personal differences. Indeed, all that is stated here should be understood not as occurring wherever there is an emotional crisis, but only where certain special and often obscure conditions are fulfilled.

The following diagrams illustrate some of these temporal relations and their individual variety. The number of hours or minutes given are of course subject to considerable error.

Student in Earthquake of 1906

Day Before		Morning of Earthquake	Five or Six Days Following
Early part	Evening	Most vivid and full.	Disconnected memories.
Nothing.	Fairly vivid.		

Student in Earthquake of 1911

Preceding Time	The Crisis		After-time	
About one or two hours.		About 1 hr.	About 3 hrs.	5″–10″ later
Very clear.	Very clear.	Greatest vividness.	Recalled.	Vividly recalled.

Accidental Shooting of the Student's Sister, 4½ Years Before

Preceding Part of Day	Shortly Before	Time of Accident (2:30 P.M.)	Shortly After	Latter Part of Day	Next Day
Vivid.	Most vivid.	Most vivid.	Most vivid.	Less vivid.	Normal.

INTENSE SURPRISE, ABOUT 8 MONTHS BEFORE

Preceding Time		The Crisis	After-time	
Half hr.	Quarter hr.	Hr. and a half	One hr.	Later
Exceptionally vivid.	Vague.	Least distinct.	Vivid.	Nothing is distinct.

2. ITS QUALITY

Many of the persons whose experiences I have been permitted to use have testified to the unusual vividness and fullness of these antecedent effects. In some cases the memories preceding the crisis are not only far more vivid than those which accompany and follow it, but they are more vivid than any other of the person's memories, save the most recent.

"I remember numerous little 'nothings' that I can remember of no other particular day," writes one of my reporters, of a time beginning hours before an automobile collision six years ago. "It is as if I were seeing this one day and night through a pair of powerful glasses while I view the other days with just my own eyes, and see their events with almost a gray fog over them."

Another writes: "Events previous to the time of my being struck by the train stand in bold relief. I should say that the events of the five minutes previous are as vivid now (after 3½ years) as are any events two days past. I believe I can account for every move of these five minutes. The time is completely filled in my memory."

The vividness according to these reports is not confined to visual images: sounds are often clearly represented, the precise wording of a conversation, the thoughts which entered into the conversation or which silently passed through the person's own mind, the mood, the general state of mind. Far more frequently, however, there is a vivifying of the pictorial aspect of the experience. But between or before such vivid stretches there are occasionally events recalled "in general," that is, they are clearly known to have occurred, yet they are represented in no living fashion. Personal differences also appear in the ratio of the vividness preceding to that which accompanies and follows the crisis. In some cases instead of the relation mentioned where the preceding was more vivid than the succeeding, there is found an opposite relation: the later out-tops what goes before.

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Among the preceding examples, there are sufficient illustrations of a greater vividness before the crisis. The following will further illustrate equal or greater vividness of what accompanies and follows the crisis.

Automobile Accident, Summer of 1915: "I can remember the details vividly for about ten minutes before the accident. Before that I have only a general recollection that we were riding along and that I was trying to read. But I can remember the details vividly for a much longer time after the accident. The vividness extends for about two hours or more."

Earthquake when Seven Years Old: "I can remember vividly back as far as about noon of the day preceding the earthquake. I remember just as vividly the day of the earthquake and for a week after. But for about a month after, I recall many things; and although the events are vivid, still there are some empty spaces."

Earthquake of July, 1911: "The minutes of greatest vividness for me are those immediately following the earthquake for about one hour; then another period of vividness about four hours later; that later period of vividness only covers a period of a few minutes.

"Memory of events for about two hours before crisis is very clear."

The most striking fact is the odd selection emotion makes: it sharply picks out certain stretches of experience for one effect and a neighboring and apparently equally inviting stretch for the very opposite effect. The sharp delimitations and reversals of its effect in one and the same mind are extraordinary.

3. Frequency

My data indicate that the retroactive effect is by no means of rare occurrence. Among some 225 persons from whom reports have been received, as many as twenty-five have given me detailed accounts in which this appears. Nor does it seem to be confined to a single limited period of life. There are cases where the effect has come at some crisis in very early childhood. In other cases it has occurred at a later date. I am not clear whether or not the effect is of more frequent occurrence among women than among men.

There is some indication, but not wholly reliable, that the women experience it the more frequently.

4. Causes and Conditions

The peculiar quality of the emotional excitement seems of far less importance in producing the result here described than the intensity of the shock. In some cases fear is the exciting emotion. In other cases it is shock without fear, having more the nature of fearless surprise. In other cases it is sudden and deep sorrow. In still others it is markedly pleasurable surprise. If it is found by later evidence that this phenomenon of retroactive hypermnesia is of more frequent occurrence among women, one would be tempted to ascribe it to the greater mobility of their emotions. Nor would it be surprising to find that this greater emotional mobility, this lower threshhold of emotion in their case, explains also the general mnemonic superiority of women, indeed that this and the emotional hypermnesia, concurrent as well as retroactive here discussed, are but different effects of a common cause.

The retroactive effect does not in most cases seem to me to have been caused by a frequent review of the experience, as though the interest in the emotion-giving event had caused something like a deliberate and repeated attempt to connect it with the events which led up to it. The reason for rejecting this explanation is the qualitative difference between these antecedent memories and the memories of all or almost all other events, and which are frequently counted as of far greater importance. The resemblance which the antecedent vivifying bears to that which is concurrent with the emotion indicates that both come from the one source. But it is doubtless true that in some cases there was this later review, and the items are recalled not because of some immediate effect of the emotion, but by an indirect effect, by giving a motive for an interested and one might almost say a deliberate attempt to recover them.

One can as yet only surmise the cause of opposite effects in different persons. It may either be that they have a decided

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difference of emotional mobility, or else that their psychophysical organization is such that even with the same quality and intensity of emotion the sudden rush of intense currents does not have the same fixating effect upon the traces of former experience. But still more obscure is the opposition of effects in one and the same person,—I mean not only where the antecedent events are now intensified and now suppressed, and this in irregular stretches, but also where the events preceding are intensified and those which accompany and follow the crisis are reduced in liveliness. It would appear that there are certain limits of intensity within which an emotion vivifies backward or forward. If this intensity is exceeded the experiences connected with it are in some degree suppressed; while if it is not reached the experiences are lost, not so much by an active suppression as by a mere failure to gather up the events into the mesh of interest. The effect of emotion would seem to be analogous to that of certain drugs, where a certain dose excites, while a still greater dose depresses.

Since it is undoubtedly true that emotion facilitates the recall of whatever is noticed during the excitement, and since it is probable that memory images are not different in kind from images of perception, there would seem to be no reason why these memory images should not be treated by the emotional onrush in precisely the way that the perceptive images are treated. An obstacle in the way of such an explanation of the retroactive hypermnesia would be that preceding experiences, especially those of hours past or of the preceding day, probably do not at the time of the emotion exist in the form of actual images. Their existence is rather in the form of psychophysical dispositions or traces, prearrangements by which the image may under suitable conditions become actual.

The emotion, then, would seem to have the power to go behind mere imagery into these dispositions or traces, and to strengthen them and the connections by which they may be called into life. And not only the traces of the experience which aroused the emotion, but also of trivial and neutral events antecedent to the emotion itself.

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